A Study of

The Impact on the UK of Climate Change Impact in Other Regions of the World

Book 1

Impact of Impact

Anthony Hodgson
Graham Leicester
Daniel Wahl
Rebecca Hodgson

Decision Integrity Limited
and
The International Futures Forum

This document is not a statement of government policy

Acknowledgements

The authors would like to thank the following people for their contributions to the project: Robert Horn for the *infomural* on the next 50 years that he authored for the World Business Council for Sustainable Development and which he introduced to the 'Hard To Imagine' workshop, guiding the discussion; Vic Henny, David Hodgson and Bill Sharpe for their stimulating participation in the same workshop; Ian Page and Bill Sharpe for stretching our thinking about the nature of the impact of climate change on resource scarcity; Noah Raford and David Hodgson for horizon scanning; Alexandra Hodgson for designing the World System Model impact method and graphics; Alastair Hall for disciplining and compiling the references, and Ragne Lowe for help with proof reading. The authors would also like to thank Gareth Alston and Louisa Gilmore of Foresight for their supportive and determined scrutiny to improve the clarity of the work.

Decision Integrity Limited www.decisionintegrity.co.uk

International Futures Forum www.internationalfuturesforum.com

Contents Page

Book 1 – Impact of Impact

Introduction

SECTION 1 Methodology

SECTION 2 Assessing Climate Change Impacts and Vulnerabilities

SECTION 3 Climate Impact Mapping – Direct Impact Patterns

Book 2 – World Stories and Wider Implications

This is a separate companion to Book 1 which has three sections:

1 World Stories –

Background Scanning, Mapping and Critical Systemic Interactions

These are extended accounts of climate impact in the seventeen countries and regions which amplify and support the data in the Direct Impact Patterns in Section 3. References in this section are consolidated with those in Book 1 Section 6 – References.

2 The Non-Linear Nature of Climate Impact

This is a systems analysis of the theoretical basis for accounting for non-linear behaviour drawing on systems dynamics theory

3 High Impact Low Probability Events

This is a set of ideas generated in a workshop on 'Hard to Imagine Implications of Climate Change'.

Introduction

1 The Brief

As a contribution to the UK Government's National Adaptation Programme, DEFRA is carrying out a Climate Change Risk Assessment to identify risks from climate change to the UK. Foresight is contributing to that process with an International Dimensions of Climate Change programme (IDCC) to consider how climate change occurring overseas might have a consequential impact on the UK.

This report forms part of that programme. It builds upon a set of systems maps and other visual representations, which describe important systemic impacts around the world and possible consequences of special interest to the UK.

This project is breaking new ground. Hence, as well as creating a set of systems maps and accompanying explanations, the project has developed a methodology for this kind of systemic analysis, sufficiently tested and transparent, to offer a useful framework for subsequent adoption and refinement by policy makers and analysts in the UK and elsewhere.

The original project brief notes that: "*With a few exceptions (e.g. sea level rise which displaces populations that might seek to move to the UK), climate change will not act in isolation, but will interact with many other socio-economic effects*."

The systems maps focus on those aspects of the social ecological system in a geographical locality where climate change is likely to make a substantial difference. Aspects of climate change occurring elsewhere in the world unlikely to have significant implications for adaptation in the UK are included

in the overall analysis, but the focus of this report is on the secondary impacts on the UK.

The project brief also required the design and delivery of a workshop to explore 'difficult to imagine' ways in which climate change and the drive to a low carbon economy could affect the UK, and to help identify any blind spots in conventional thinking. The summary and results of this workshop can be reviewed in Book 2 Section 3.

2 Outline of the Approach

Systems mapping, adopting a systemic perspective, was used as the fundamental approach for this work in order to address the evident complexity and interconnectedness of the subject matter. Book 2 Section 2 contains a brief essay on systems thinking and its usefulness in this kind of context including such properties as complexity, non-linearity, second and third order interactions and tipping points. In particular it explores the non-linear nature of climate change impacts and the typical system behaviour of 'overshoot and collapse' common in systems from ecosystems to whole civilizations.

Climate change impacts are complex in three primary ways:

- The science of climate change is inherently complex with a high degree of uncertainty

- The impact of climate change is a function of a whole range of socio-ecological factors which themselves are complex in their own interactions

- The human/ecological/climate as a total system is in many ways reflexive: i.e. what happens next depends on both human and environmental system responses. It is inherently a non-linear complex adaptive system.

Beyond this, the report addresses a further level of complex interaction. It does not look at the *direct* impact of climate change on the UK, but rather addresses the question:

> *"What might be the impact on the UK of the impact of climate change elsewhere in the world?"*

Few of these possible consequential impacts are direct one-to-one relationships. Mostly they are mediated through markets, international institutions and other global coordination mechanisms. However, there are also some highly specific direct dependencies (such as the vulnerability of specific sources of rare raw materials).

At the heart of the study is a thorough review of peer reviewed synthesis literature and other expert work in the various fields relevant to assessing climate impact. This review draws in particular on the large volume of synthesis research reports produced in the run up to the UN Climate Change Conference in Copenhagen in December 2009. The majority of the detail relating to climate change in this report, particularly the detailed in Book 1 Section I, is quoted from these reports. They are all referenced in the bibliography in Book 1 Section 6.

In order to appreciate the systemic, interconnected nature of the interactions between different factors, the analysis of this material has used the framework of the World System Model (IFF World System Model 2010) – an existing framework for considering system viability at global, national, local, community and other recursive levels. The system model is described in more detail in Section 2 of this report. It is used to assess the direct impact of climate change in other parts of the world (for example on food, energy, infrastructure and water) and the consequential systemic interaction of those specific direct impacts.

Other countries and regions will themselves be planning for adaptation, mitigation and climate risk management – some more effectively than others. Hence in order to appreciate the differential impact *in practice* of climate impact elsewhere, a measure of adaptive capacity or societal resilience has been estimated for each country and region under consideration. This allows an overall measure of *vulnerability* to climate change impact in different parts of the world; vulnerability being a function of a country's exposure to climate risk and its likely capacity to cope in the eventuality that the climate change impact occurs.

In Section 4 the report draws out the implications of these vulnerabilities elsewhere in the world for significant systems in the UK.

The report does not explicitly address different scenarios for the pace or severity of climate change. This too is a further, legitimate, area of complexity and uncertainty. The analysis presented here could be repeated (if desired) for different climate scenarios. The intention of this report is to:

- establish a robust methodology for dealing with the multiple layers of complexity involved;
- provide an immediately useful set of provisional conclusions for the UK as the result of applying that methodology for the first time.

Hence the information used to populate the analysis assumes significant climate change impact (evidence-based) but with no more specific time horizon than that adopted for the IDCC programme overall (namely 2050 – 2100).

In providing both a methodology and a first compilation of detailed content, the report is intended to provide an inter-disciplinary platform for further elaboration and improvement by specialists and other experts in the field. At the same time the initial analysis yields significant immediate conclusions for policy and practice. The report engages with the global system in all its complexity, encouraged by the observation of management and learning

theorist Russell Ackoff that '*a partial solution to a whole set of problems is better than whole solutions to each of its parts taken separately'* (Ackoff 1999).

This work is intended to stimulate policymakers and decision makers in both the public and private sectors to consider the threats and opportunities that the impact of climate change impacts elsewhere may bring for the UK. In the world of practical affairs judgments often have to be made before undisputed evidence is available. That is undoubtedly the case in this area. As such, the report and its novel methodology seek to contribute to the interface between the ongoing synthesis of scientific findings and the world of practical affairs.

SECTION 1 Systems Methodology

1.1 Applying a Systems Thinking Approach

The aim of this report is to offer a holistic approach to assessing how the potential impacts of climate change elsewhere in the world might in turn impact on the UK. It assumes that any specific impact will be taking place within a complex situation so that single causes may have multiple effects. For example, reduced water availability may change an ecosystem in many different ways: it will affect both food production and community health.

There are three levels to this inquiry:

- First, a review of the available scientific literature and other reports on the potential impact of climate change on the world system, region by region;
- Second, an investigation into how simultaneous climate change impacts in different parts of the world may produce effects that will act on each other, in a cumulative or ameliorating way;
- Third, an exploration of what might be the consequential impact of these international dimensions of climate change on the UK.

Scientific predictions of potential climate change impacts anywhere in the world are an attempt to forecast the behaviour of a complex dynamic system. Such systems are by definition unpredictable and uncontrollable beyond very limited spatial and temporal scales (Hastings 2010). The attempt to forecast how climate change impacts may impact on economic systems, global resource markets, institutions of governance, global security, or communities everywhere takes the degree of ambiguity and unpredictability to another level.

This report breaks new ground in holistic thinking about climate change and its potential impact on a set of interconnected and interacting vital conditions for community resilience and adaptability everywhere. The authors have

employed a series of new frameworks for whole systems analysis and transdisciplinary synthesis.

The report draws on a number of principles inherent in systems science:

- Whole systems have properties not attributable simply to a sum of their components – the overall effects of climate impact have emergent interactive consequences;

- Effects can themselves be causes leading to feedback loops with non-linear properties – for example temperature rise over the tundra leads to a melting of the permafrost and a release of methane previously trapped in the icy ground. Methane is a powerful greenhouse gas, which then contributes to temperature rise and accelerates the further release of methane (Wasdell 2007). This type of dynamic process can generate tipping points where sudden changes occur (See Figure 1.1);

- Ashby's Law of Requisite Variety suggests that a region's adaptive capacity depends on the diversity of options it has available to respond to the real complexity of the situation on the ground (Heylighen 2001);

- Patterns of connectedness determine behaviour over time more strongly than simple linear causation – for example ingrained policy or cultural patterns may determine how vulnerable a community is more than its apparent capabilities for action;

- Slow variables within complex dynamic systems can often be overlooked and once they reach and surpass critical thresholds can cause the entire system to undergo a rapid period of reorganization and change until it settles into a different (and often less diverse and productive) state (Walker 2006).

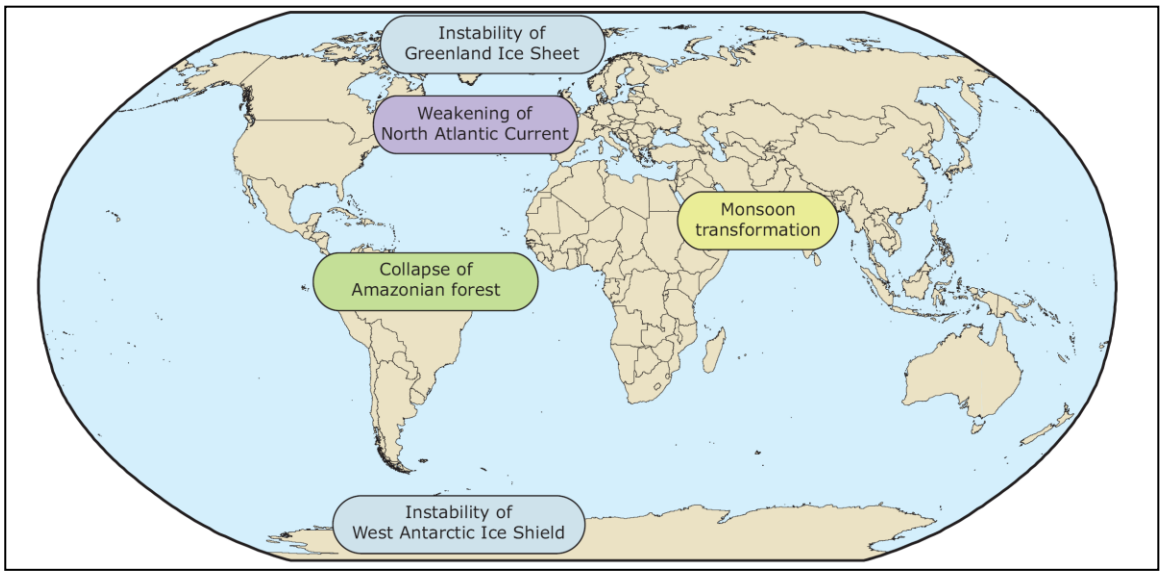


Figure 1.1 – Some of the major possible non-linear changes in the global climate system (Climate Change as a Security Risk, German Advisory Council on Global Change (WBGU 2007)

1.2 System Mapping in the Context of this Report

Recognising the complex nature of the processes in question, the brief for this project required the development of a set of 'systems maps' to help understand the possible behaviour of the world system under the impact of climate change. The term 'systems map' is used here in the sense of a visual representation of the area of interest that helps to depict multiple interconnected variables with feedback. In this usage it is not the same as a geographical map. System maps are representations of mental models, which help articulate an overview of situation emphasising interconnections.

A system map functions like an architect's sketch, showing the form and structure rather than the detail of a completed building. The architect's sketch provides a mental model that anticipates the form the building itself might take, subject to engineering and site analysis, quantity surveying and economic costing. It aims to depict the potential and form of the building in a way that allows the client to visualise its suitability for purpose. In the same way, a system map serves as an interpretive judgment of a situation, referred to by

Vickers (1995) as an ‘appreciative system’. This role of system maps should not be confused with or mistaken for mathematical modelling of physical systems such as climate.

The role of the system maps is to act as a bridge between the ‘world out there’ as reflected through the investigative lens of various scientific disciplines and the pragmatic design of policy. System maps serve as a link between the findings and evidence of science and the implicit cognitive maps of decision makers.

1.3 The IFF World System Model

The particular form of system map used in this report was initially created by Anthony Hodgson in 2007/8 and has since been developed (Hodgson in press 2011) by the International Futures Forum. (IFF World System Model 2010) This is referred to as the IFF World System Model, the basic structure of which (slightly adapted in its language in order to suit this specific project) is illustrated in Figure 1.2.

The IFF World System Model has 12 nodes, each of which is considered an essential component of a viable or sustainable human society in its natural and social environment. The terms are deliberately kept simple and basic so they can operate at many levels of recursion (for example at the scale of villages, cities, bioregions, countries, continents, and the whole planet). Between the 12 nodes there are 66 binary connections. These binary connections serve as a heuristic for identifying systemic linkages that might otherwise be overlooked.

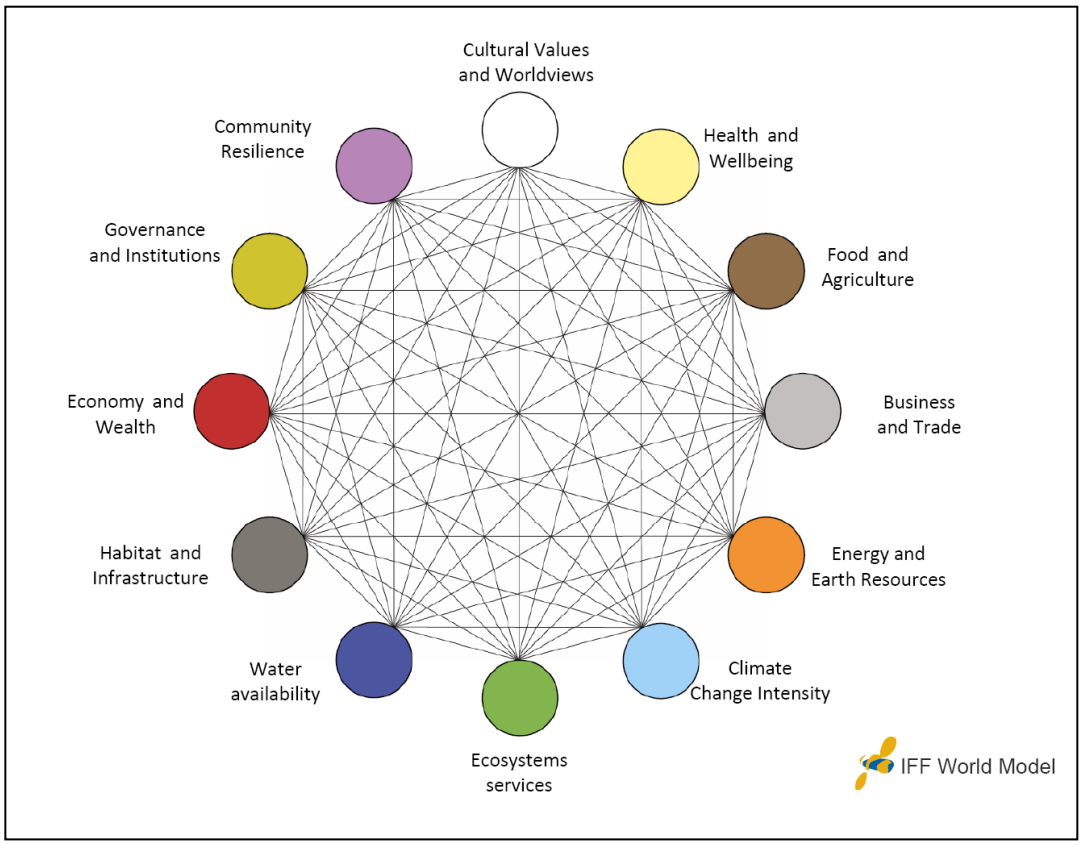


Figure 1.2 – The IFF World System Model with the twelve nodes of the social-ecological system

The World System Model can be used as a scanning tool to find concurrent and converging impacts from different domains. It allows us to track interactions between trends in the different nodes; and to appreciate reflexive behaviour in which responses to crisis in one domain trigger a crisis in another domain. For example, the model provides a framework to map the impact of a financial crisis on employment and hence on community resilience. Or to discover the possibility of intervention in one node triggering unintended consequences elsewhere: for example the view held by some that a rise in food prices is associated with promoting biofuels.

The node descriptions are deliberately kept as simple, high-level summaries but they each give a position for a number of aspects that influence a particular node. Some of these aspects are listed in Table 1.1 (the list does not claim to be exhaustive).

Health and Wellbeing	population health, sense of security, addictive behaviour, degree of happiness, self-responsibility, creative expression, …	**Water Availability**	rainfall and ice-melt patterns, the state of aquifers, rivers and lakes, irrigation and industrial demands, purity and distribution, scarcity and contamination, water security, …
Food and Agriculture	agriculture and horticulture, food quality, nutritional balance, food safety, equitable distribution, methods of production, geographical distribution, …	**Habitat and Infrastructure**	settlements on all scales, infrastructure and utilities and their vulnerability, design quality, work-life relationships, degradation and restoration, urban ecological footprints, supply chains, security resources, …
Business and Trade	commodities and their availability, geography and cost, transportation of goods, mobility of people, free/fair trade, markets and agreements, regional economies, trade support systems, …	**Economy and Wealth**	finance and economy, values and life-style, work and reward, equity and distribution, monetary systems, freedom and regulation, …
Energy and Earth Resources	fossil sources, renewable resources, nuclear sources, energy intensity and efficiency, distribution and application, energy security, the realism of transition to a low carbon economy, …	**Governance and Institutions**	geopolitical systems, global corporations, civic participation, regulation and subsidies, exploitation, corruption and oversight, public order, security, organised crime and terrorism, general response to crisis and emergency, …
Climate Intensity	weather patterns, greenhouse gas emissions, temperature rise, ice melt and sea level, mitigation activity, its success or failure, current and predicted impact on different regions, …	**Community Resilience**	life span education, civic capacity, social capital, competition and mutuality, resilience, tribal identity, migration and immigration, tourism, …
Ecosystem Services	the state of organic life, species extinction, wilderness, forms of pollution, exploitation and degradation, conservation and restoration, the general capacity of biosphere to sustain conditions for the healthy life of communities, …	**Cultural Values and Worldviews**	dominant belief systems, tolerance and fundamentalism, values and outlooks, ideologies and utopias, fixed or dynamic attitudes, the place of consciousness, the intrinsic and extrinsic value of nature, …

Table 1.1 Expansion *of the content of the twelve nodes of the IFF World System Model*

1.4 Climate Change Impact Data

The critical first task in undertaking this study was to select from the available research literature on climate change impact and to map the results on to the World System Model – broken down by significant countries and regions.

The scanning of the data assumed a general scenario in which temperature rise is sufficient to manifest significant climate impact. No attempt was made to predict when any such impacts might occur. Given the inherent unpredictability of such impacts (Ditlevsen 2010) the emphasis was on the issue of what kind of impacts might be anticipated within the broad scope of the project outline (up to 2100), rather than precisely when they might occur.

A good first source for relevant data was the volume of peer-reviewed synthesis reports on the global and regional status of knowledge on present and future climate change impacts around the world produced in the run up to the UN Climate Change Conference in Copenhagen in December 2009. These reports (referenced in Section 6) originate from such bodies as the International Panel on Climate Change (IPCC), the United Nations Development Programme (UNDP), the US National Intelligence Council and the European Environment Agency. It is reasonable to assume that the process of scrutinising the scientific evidence on climate change and the primary data employed by such organisations are rigorous and balanced. This type of report provided the bulk of the information base. References in the text of this report allow the critical reader to refer not only to the synthesis report but also to original sources on which those reports draw.

This information was supplemented by various reports of similar provenance issuing from UK Government agencies including DEFRA, DECC, The Met Office and the MoD.

However, the above sources were not comprehensive in their coverage of all the regions of interest, especially for impacts at local level. These gaps were

filled by consulting more local resources including those of such organisations as the African Partnership Forum, the Australian Department of Climate Change, the Stockholm Environment Institute and the German Advisory Council on Climate Change.

This still left gaps in certain perspectives of interest in areas such as food security, embodied water and health and wellbeing. The most comprehensive studies accessed on these issues were by such organisations as WWF, the New Economics Foundation and the Pew Centre for Climate Change. These reports were selected for their coverage and referencing of peer reviewed literature.

In compiling and evaluating this literature a significant background expertise helped to test for its quality and relevance.

Firstly, a number of Fellows of the International Futures Forum are world experts in global and futures thinking. Their knowledge of the field was a constant source of advice to the project team, including for example Professor Wolfgang Michalski, former Director of the OECD Futures Programme; Professor Kees van der Heijden, leading author on scenario planning and visiting professor, University of Oxford; Professor William Sharpe, formerly Director of Research at Hewlett Packard and a frequent Foresight author; Martin Albrow, Professor Emeritus at the Centre for Global Governance, London School of Economics.

A special participant in the project was Robert Horn, Human Sciences and Technology Advanced Research Institute (H-STAR), Stanford University. His advice to the project drew on his work as synthesiser on the 50 Year Vision of the World Business Council for Sustainable Development (WBCSD). This work itself included as advisers: Professor Angela Wilkinson, Smith School, University of Oxford; Professor Barry Carin of the Center for Global Studies, University of Victoria, Canada; Professor Hunter Lovins, Presidio Graduate School, San Francisco; Alex Pang, the Institute for the Future, Palo Alto;

Mathis Wackernagel, Global Footprint Network; Professor Thomas Homer-Dixon, University of Waterloo, Canada; and Celina Realuyo of the National Defense University, Washington.

The climate scanning analysis was led by Dr. Daniel Wahl who has twelve years of experience in the field of sustainability research, education and consultancy. As a contributor to the State of the World Forum he has been part of an international team of climate and sustainability experts communicating about the most recent climate change research including Lester Brown of the Earth Policy Institute, Bill Becker who headed the Presidential Climate Action Project in the USA and Jasper Sky, the coordinator of the Dangerous Climate Change Project at the University of Oxford.

1.5 Climate Change Direct Impact Patterns

There are seven nodes of the World System Model that are most susceptible to direct impact by climate change. They are:

- Health and wellbeing
- Food and agriculture
- Energy and earth resources
- Ecosystem services
- Water availability
- Habitat and infrastructure
- Community resilience

The diagram in Figure 1.3 shows the systemic connections between climate change and the seven areas most susceptible to direct impact.

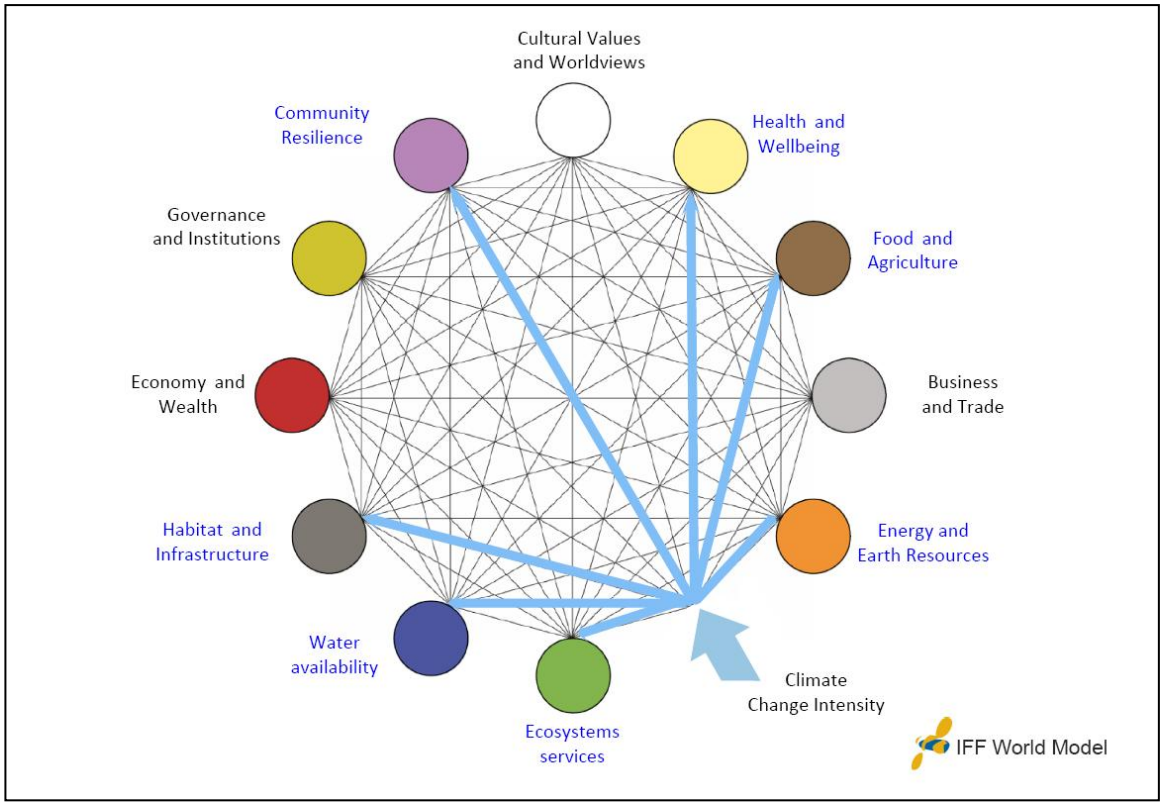


Figure 1.3 - The Areas of Direct Climate Impact in the World System Model

The remaining nodes in the model are also essential for viability of the social ecological system, but tend to be impacted by climate change more indirectly, usually through some kind of knock-on effect. Thus governance and institutions and cultural values and worldviews are likely to be critical in terms of the *response* of a country or region to potential or actual climate change impacts. Impacts on business and trade and economy and wealth are likely to be 2nd order *consequences* of direct climate impact in the other nodes. Hence the other four nodes of the model are considered in a different way in this study, under consideration of adaptive capacity.

The seven direct impact nodes were used as a heuristic or search framework for reviewing the literature for specific countries and regions. The framework revealed critical interconnections in the literature between the seven nodes. The data for each country and region recorded in detail in Book 2 Section 1 are categorised according to paired interconnections between the seven

nodes in order to allow a greater appreciation of the systemic nature of climate impact in these areas.

Finally, the data are also summarised in Section 3 in a diagram based on the World System Model showing the relative impact of climate change on each of the relevant nodes. The size of the circle for each node impacted reflects the severity of the anticipated impact. The representation on the World System Model allows for easy cross-comparison of these 'Direct Impact Patterns' between countries and regions. These judgements are also recorded in Table 2.1 in the next Section.

These assessments of severity of impact – high, medium or lower (where lower still means significant) - are inevitably the result of judgement calls by the authors based on the evidence and conclusions provided in the available literature and basic knowledge of the ecology of the region in question. A more rigorous, focused and in-depth analysis would be possible for any region and for any node – but the approach in this report has of necessity favoured breadth of coverage to fulfil the global brief, whilst hopefully pioneering a methodology that others can follow with greater rigour around specific questions as necessary.

1.6 Assessing Impact on the UK

As noted, the IFF World System Model was used as the framework for understanding climate impact on other parts of the world in a systemic fashion. That impact was then modified by a consideration of the adaptive capacity of the countries and regions in question so as to give a more accurate measure of overall *climate vulnerability.* This is explained in more detail in the Section 2. It is this measure of vulnerability to climate change impacts that provided the input to a consideration of the possible consequences for the UK: the possible impact on the UK of climate impacts elsewhere in the world.

To maintain a consistent systemic perspective, the World System Model was also applied to map the impact on the UK of climate change elsewhere. However, for this purpose a slightly different set of nodes was considered. For example, a primary factor in the impact from elsewhere on the UK is the capacity of the UK governance and institutions to cope in an international context, so the governance node was also included, On the other hand community resilience was excluded as a factor relating to the UK's own adaptive planning and response capacity which is not part of this study. The eight nodes selected are shown in Figure 1.2.

The four excluded nodes are considered aspects of the UK's domestic adaptive capacity, namely: *ecosystem services* directly impacted by local climate change on UK's ecology; *climate change* treated only as the global source of impact; *community* resilience considered as part of the UK's adaptive capacity; and *cultural values and worldview* considered to be specific to the UK itself (although this will reflect to some extent the diversity of the UK's ethnic, religious and other social groupings and their associated belief systems about climate change).

A search was made for specific dependencies and interdependencies which could affect the UK supplemented by a series of reports commissioned by Foresight, Defra and others addressing critical issues for the UK.

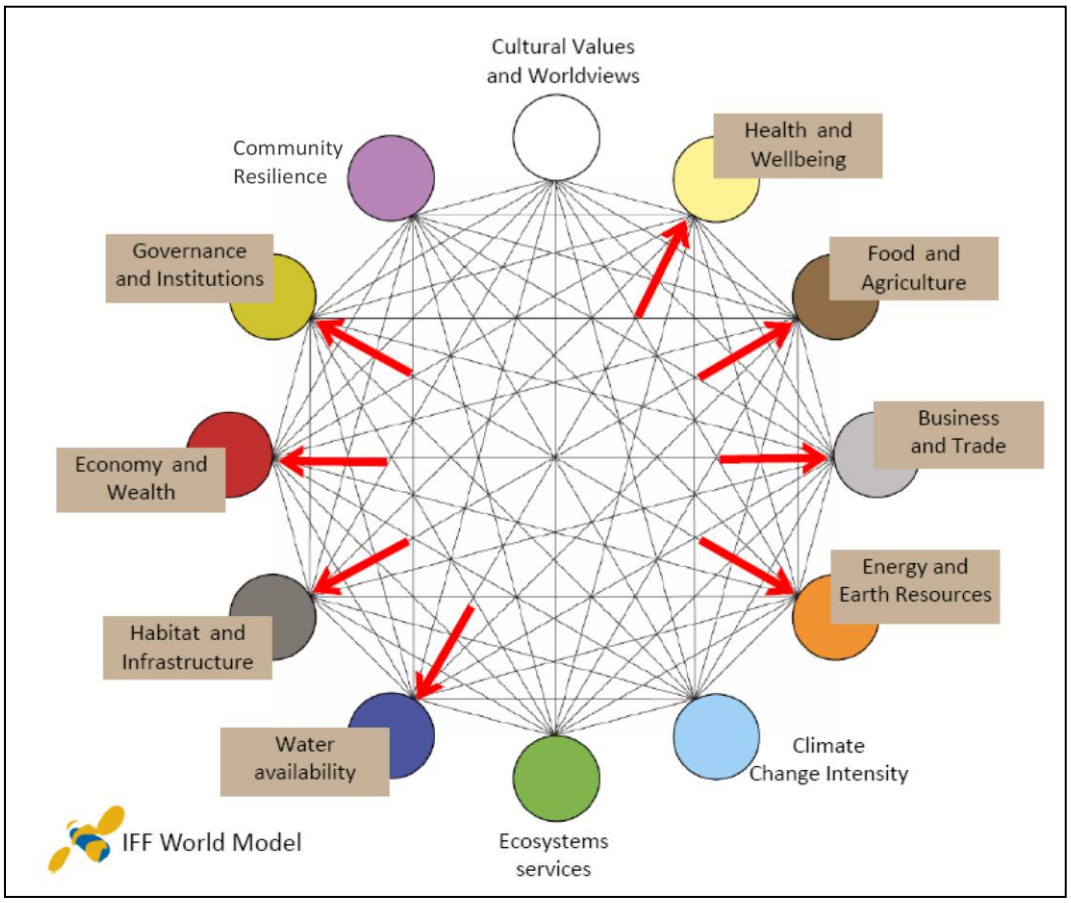


Figure 1.4 – The eight nodes of the IFF World System model selected to review impact on the UK of Climate Change Impact elsewhere in the world.

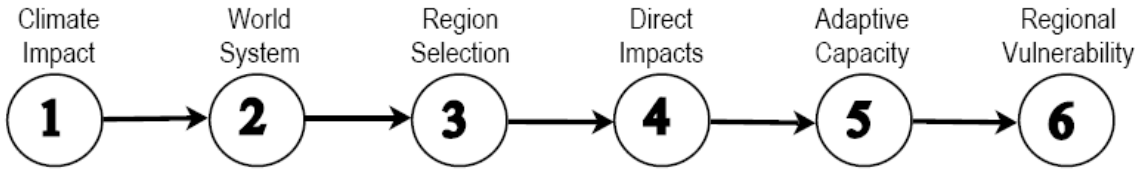
This information was then compared with the vulnerabilities identified in other countries and regions to identify specific potential impacts on the UK, and their likely origin. Specific aspects of each node were then reviewed to illustrate how to take the analysis to the next level of depth. Where possible a basic grading was applied to the geographically distinct sources of impact. The summary conclusions from the exercise overall were then represented through the use of coded geographic world maps and other types of systems maps based on the IFF World System Model.

The following sections provide a detailed step by step guide to the process and the results.

SECTION 2 – Assessing Climate Change Impact and Vulnerability

Introduction

In this section six steps, from considering climate change impact through to estimating regional vulnerability to climate change impacts, are explained. The steps are summarised in the chart below.



1. Climate Impact – the basis for identifying the direct impact of climate change on different regions and countries
2. World System – the IFF World System Model which is applied to each region or country
3. Region Selection – the basis for selecting the set of regions and countries studied
4. Direct Impacts – the estimates of the nature and degree of impact in each of the selected regions or countries
5. Adaptive Capacity – the estimation of the adaptive capacity of the selected regions and countries based on proxy indicators
6. Regional vulnerability – the product of direct impact and adaptive capacity, which gives some indication of the possible state of a region or country assuming climate impact

The reasoning behind this sequence of steps is summarised in the flow diagram Figure 2.1. Essentially, to arrive at regional vulnerability the preceding steps are logically required to build up the necessary information.

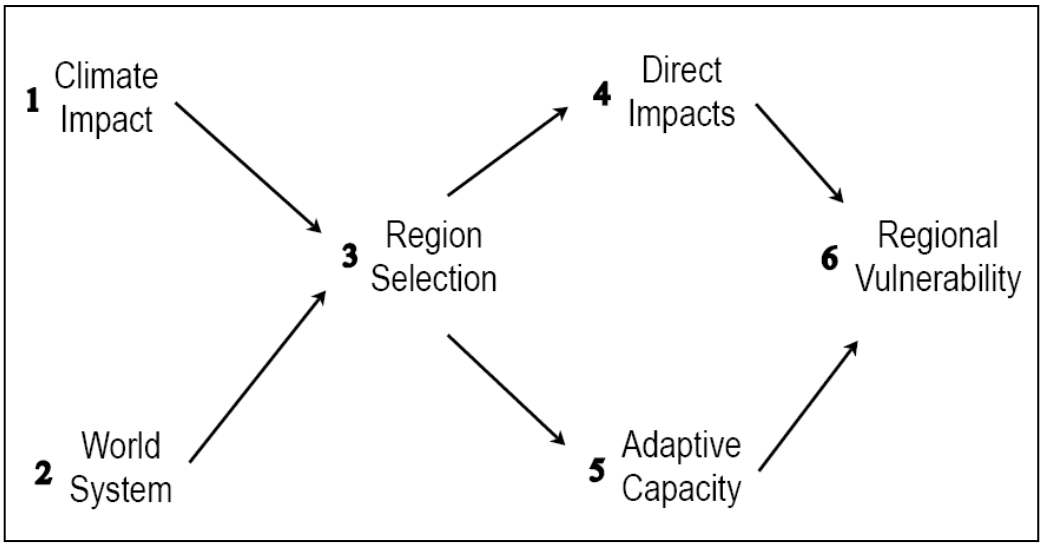
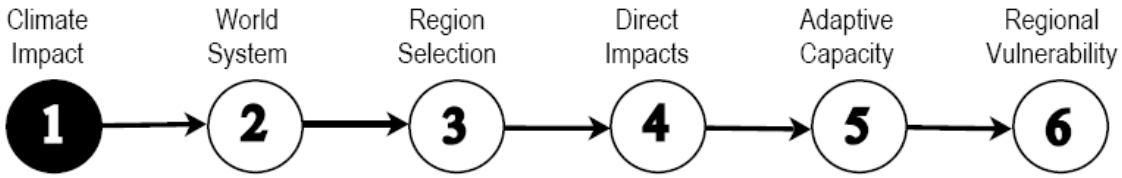


Figure 2.1 - Flow chart of the methodology *to arrive at vulnerability*

To assist the reader in following the sequence this header is repeated at the start of each step explanation and the specific step addressed is highlighted.

2.1 Regional Climate Change Impacts



As noted in the previous section (Section 1), a great deal of research material on the potential impact of climate change has been generated for different countries, regions and the world as a whole. Even so, the availability of detailed data and modelling is still uneven across the globe, with fewer reports available for the Middle East and Central Asia in particular.

Since 2005 the number of publications on climate change impact has risen sharply. In the lead up to the UN Climate Change Conference in December 2009 many institutions and country bureaucracies reviewed the state of research on climate change and its potential impact on their area. This generated a wealth of synthesis reports. The authors examined over seven hundred such documents in order to address the first question addressed in

this report: "Supposing we will have to face fairly severe climate change scenarios over the next one hundred years, what is the likely impact of climate change in different parts of the world?"

There is significant variation in the scenarios for climate change developed by the Intergovernmental Panel on Climate Change (IPCC) and other research bodies. This variation is reflected in the synthesis reports on climate impact. This project assumed a more severe scenario range in order better to highlight where climate impacts are likely to occur and what kinds of systemic impact are likely to be triggered. The review of parts of the world in Section 3 and Book 2 Section 1 is therefore focussed on the potential for impact if climate change effects develop strongly over whatever time scale (but more or less within the range of the 21st century).

A great many of the reviewed reports include maps of the world summarising geographical impacts of different factors including temperature rise, sea level rise, crop failure, disease and so on. What the maps allow is a quick impression of specific high impact areas around the globe. They reveal a wide diversity of possible impacts of climate change: drought, flood, disease, heat waves, erosion, desertification etc. The same weather event, such as a cyclone, will have different impacts in different areas depending on local conditions.

It is clear from reviewing these maps and reports that in order to avoid confusion between related but distinct aspects of climate change impact and its effects some key concepts need to be distinguished. These are the distinctions that the authors draw and apply consistently throughout this report:

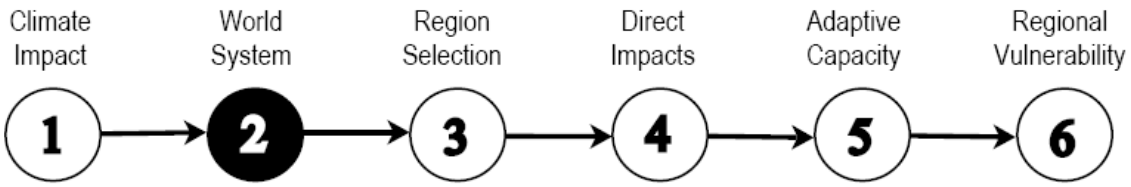
> *Direct impact* – refers to the impact in areas immediately affected by a change. For example, ecosystem services diminished or enhanced through local temperature rise.

Climate change sensitivity - refers to the sensitivity of a local or regional social ecological system (SES) to geo-physical climate change (effects on the seven primary impact nodes of the World System Model).

Adaptive capacity – is the capacity of a given region's social ecological system (SES) to adapt if direct climate change impacts occur in that region. The term applies in this context mostly to human systems, such as the economy or the system of government.

Vulnerability – this is an overall function of how far the social ecological system (SES) is capable of sustaining or restoring its functionality. It is a combination of direct impact and adaptive capacity. For example the *vulnerability* of a high impact + low adaptive capacity country is higher than that of a high impact + high adaptive capacity country.

2.2 Mapping Climate Change on to the World System Model

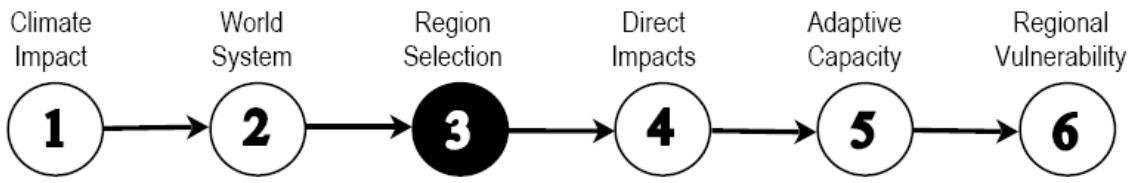


As described in the previous section on systems methodology (Section 1), to create systems maps of the many diverse impacts of climate change and focus them in specific regions, impacts were studied and grouped in relation to the World System Model (see Figure 1.2). This model was considered appropriate since it was deliberately developed to provide an integrating framework for a wide-ranging set of key variables essential to the viability and resilience of any local, regional, or national society or the world system as a whole.

The analysis was conducted, region by region, for 17 distinct climate change impact regions, based on a comprehensive review and synthesis of the

currently available literature. Two levels of analysis were conducted. Level one estimated the scale of impact on specific nodes as described in *Section 1 Methodology* subsection Figures 1.2. The resulting World System Model impacts are summarised in Section 3. Level two draws attention to paired interactions between specific node impacts. The resulting World System impact 'fingerprints' for the 17 global regions are in *Book 2 Section 1 World Stories*. These are intentionally constructed mainly from direct quotes from the source literature to emphasise the way the interconnections are implicit in the research literature. The report also considers the special case of the UK Overseas Territories.

2.3 Selection of Countries and Regions



Beyond a commitment to provide a broad global coverage, the main criteria for selection of areas for this study to focus on were:

i) countries or regions most likely to experience significant climate change impacts, that would be likely to have considerable knock-on effects throughout the world system

ii) countries or regions with which the UK has significant interdependencies or interests and where there is therefore most likelihood of knock-on effects that the UK needs to take into account.

Countries and regions satisfying the first criterion were identified by considering the geo-physical range of climate impacts and correlating these with the geo-political structure of the world. Countries and regions satisfying the second criterion were both identified in the original brief and also revealed through more detailed work on UK dependencies conducted as part of the project.

A special case is that of the UK Overseas Territories (UKOST) since they are part of the sovereign territory of the United Kingdom. In theory they should be addressed in the same detail as the rest of the UK. However, considering the knock-on consequences for the Overseas Territories of impacts of climate change elsewhere in the world would involve an intensive study of the Territories' own networks of interdependence by analogy with Section 4 for the UK. Such an additional detailed analysis was beyond the scope of the present study – but it could helpfully reveal critical dependencies and vulnerabilities which would in turn inform adaptation and resilience planning in the Overseas Territories. For now, Section 3 of this report includes a subsection with an overview of the impact areas most likely to have strategic implications for the Overseas Territories.

Two foundational pieces of work that were used to underpin the selection of countries and regions of focus in this study are the Giorgi climate regions (see Figure 2.3 and the more general geopolitical world modelling approach by Mesarovic and Pestel (1975) that divides the world into ten interacting geo-economic regions (see Figure 2.2. This needed adapting to reflect today's geo-political situation, e.g. separating Russia and Eastern Europe.

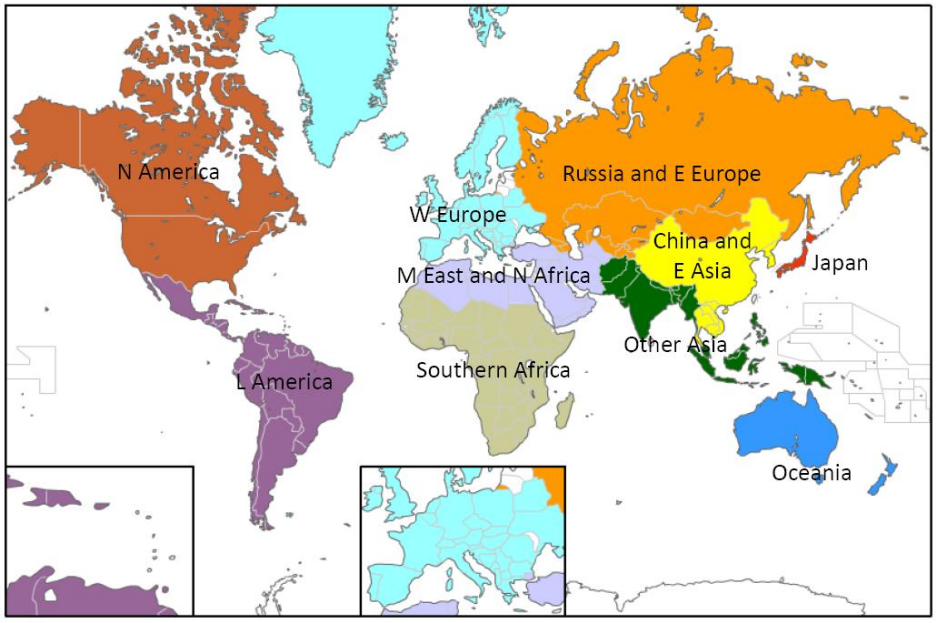


Figure 2.2 – The original *ten global regions of the Mesarovic and Pestel (1975) world model*

The combination of these various approaches and analyses led the authors to adopt for the purpose of this study a broad view of geopolitical regions, climate regions and UK dependencies to focus on seventeen regions and countries plus the UK Overseas Territories. The reasons for the distinction between regions and countries is that firstly, in some areas the reviews of climate impact are best considered at the regional level, for example Western Europe; and secondly, some countries, such as Canada and Russia, cover relatively vast areas. The seventeen selected are shown in Figure 2.3 which relates them to a map of the Giorgi climate regions. Further definition of these areas can be found in Book 2 Section 1 along with a climate impact World System Map and a more detailed review of the potential impact of climate change on each of the 17 regions.

The study does not therefore cover all of the 250-plus countries of the world in the same degree of detail. Detailed investigation of local and regional potential impact of climate is not always possible for all countries since the availability of reliable climate change impact predictions in the scientific literature is uneven. Some countries were focused on specifically, like Russia, China, Brazil, the USA and Canada. Others were included in a wider regional focus: the countries of Central America and the Caribbean for example.

It would be advisable to follow up the system mapping pioneered in this study with a more fine-grained focus on specific countries and regions if relations with the UK warranted such a focus That might include, for example, a more detailed analysis of climate change impacts on, for example, Japan, Pakistan or Bangladesh. The intention here is to provide a combination of a well researched and evidenced global picture with specific focus on a smaller number of areas of particular interest to the UK.

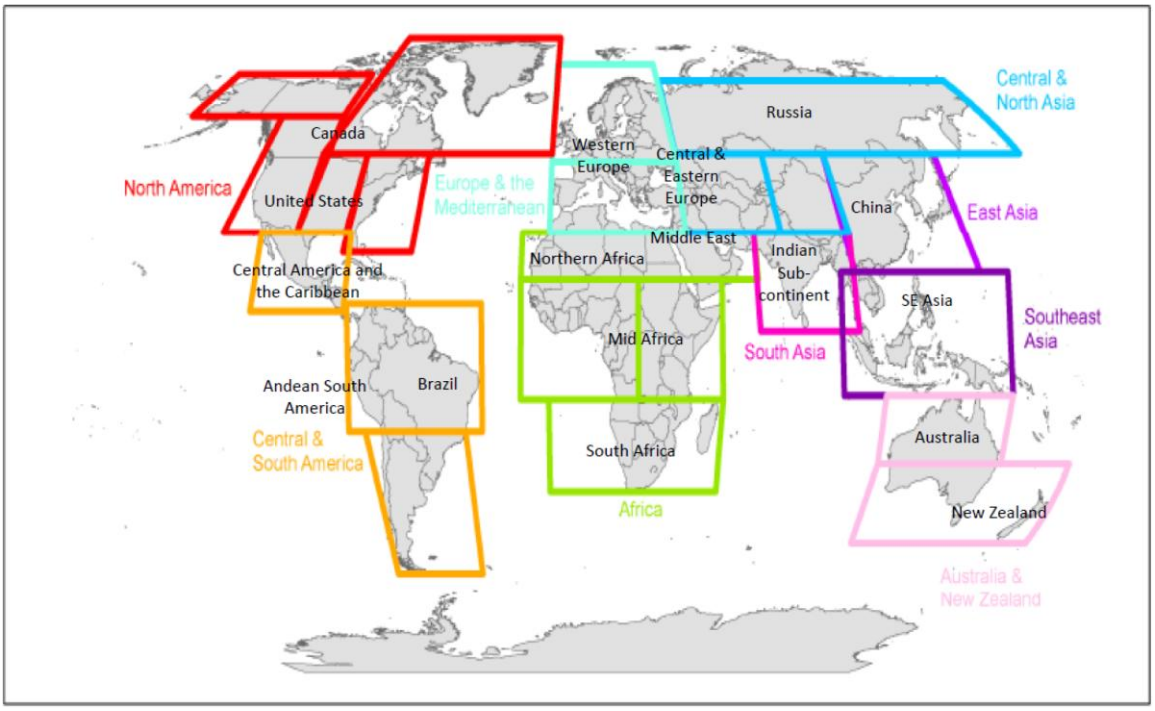
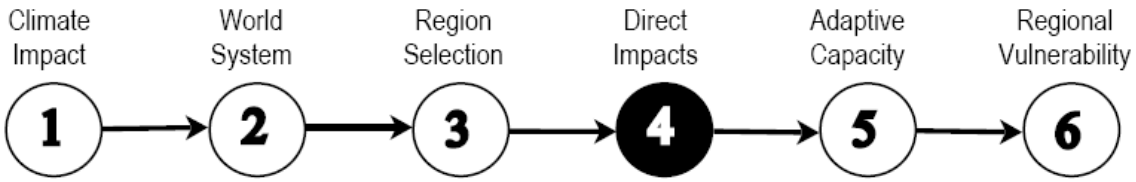


Figure 2.3 – The 17 selected regions and countries selected for the study shown in relation to the Giorgi climate *zones. They are also selected for their geopolitical significance in the context of this study. See Figure 2.2.*

2.4 Defining Direct Impact Patterns



Systems mapping goes further than simple check lists of potential impacts can towards a deeper appreciation of the overall effect of climate change impacts on a country or region. This is because it portrays simultaneously the impacts on the different nodes of the world system. The system mapping approach also provides a framework to identify potential impacts generated by interactions within the total pattern. In the absence of seeing the whole cross impact pattern, the significance of the climate change impact per se may be overlooked. For example, systems maps can help to visualize and investigate

scenarios where a set of seemingly minor impacts interact to combine into a large overall effect. The region and country reports in Book 2 Section 1 provide a platform for considering patterns of paired interactions between multiple nodes. The word *pattern* is used to emphasise the non-linear nature of climate change impact.

In reviewing the literature it is evident that some impacts are greater than others. Even though there is no comprehensive quantitative scaling for such impacts, it was considered useful to make some attempt to represent the relative 'weight' of disturbance to a particular node in a given direct impact pattern. Strong qualitative impressions were gained from the evidence and conclusions presented in the synthesis reports and these have been reflected in both a scoring system and a visual code in the impact pattern diagrams.

To compile these impressions and synthesise them into a framework for relative comparison a climate impact matrix was created (see Table 2.1) which places the seven direct impact nodes horizontally and each country or region in a vertical row. Each intersection is coloured according to the impression gained of the strength of the potential direct impact on that country or region. Impact was scored on a scale from -1 to +3 according to an increasing degree of impact (the negative number reflects the rare instances where the impact of climate change on a region is seen to bring positive benefits).

The relative scoring of the severity of the potential climate change impacts on a given node in a given country was done after in depth reviews of the available literature. The scale offers a qualitative comparison based on inter-subjective consensus among the authors informed by the current, referenced, literature. It would not be possible to construct such a matrix based on objective scientific data alone, given the unpredictability of the complex dynamic systems under study and the inconsistencies in regional scale research.

The scale used is as follows:

Grading Key	
3	Critical direct impact potential
2	Significant direct impact potential
1	Some direct impact potential
0	Little direct impact potential
-1	Possible direct positive effects

a. For a score of [3] the literature needed to suggest a major and possibly permanent disruption to the function of the SES (social ecological system) in that node of the World System Model
b. For a score of [2] the literature needed to suggest a highly stressed functioning of that node which may require a significant recovery period
c. For a score of [1] the literature needed to suggest concerns and risks in that node
d. For a score of [0] the literature made no mention of direct impact on this node
e. For a score of [-1] the literature needed to suggest a significant positive possibility from climate change in that node

These gradings are totalled across the seven areas to give a single figure representing an overall level of sensitivity to the direct impacts of climate change. Clearly, new research information or altered judgement of its weight would change the values. The result should therefore be taken as an indicative starting point rather than a definitive conclusion. However, it does provide an approximate triage of the sensitivity of countries and regions. This is explained later in Tables 2.4 and 2.5.

SYNTHESIS JUDGEMENTS OF THE POTENTIAL DIRECT CLIMATE CHANGE EFFECTS ON DIFFERENT NODES OF THE WORLD SYSTEM MODEL FOR DIFFERENT COUNTRIES AND REGIONS

COUNTRY OR REGION	WORLD SYSTEM NODE							
	HEALTH AND WELLBEING	FOOD & AGRICULTURE	ENERGY AND EARTH RESOURCES	ECOSYSTEM SERVICES	WATER AVAILABILITY	HABITAT & INFRA-STRUCTURE	COMMUNITY RESILIENCE	**RANKING TOTAL**
Mid-Africa	3	3	3	3	2	0	3	17
Indian Sub-Continent	2	3	0	3	2	3	3	16
Middle East	2	3	3	2	3	2	0	15
Central America &	1	3	2	3	3	1	0	13
SE Asia	2	3	0	2	1	2	2	12
China	1	2	0	2	1	3	3	12
South Africa	3	3	1	2	2	0	1	12
Brazil	2	3	1	3	1	1	1	12
North Africa	3	1	0	2	3	1	2	12
Central & Eastern Europe	2	2	0	1	2	2	3	12
Western Europe	1	1	2	1	1	3	1	10
Andean S America	0	3	0	2	2	1	2	10
USA	1	1	3	1	1	2	1	10
Australia	1	2	0	2	2	2	0	9
Canada	1	-1	2	2	1	1	1	7
New Zealand	0	1	0	2	1	1	0	5
Russia	1	-1	2	1	-1	1	0	3

Table 2.1 – The Summary Matrix of Potential Direct Impact of Climate Change on the seven primary impact nodes of the World Systems Model

The relative severity of potential climate change impacts on a given region are also illustrated in a '*direct impact pattern*' for that region, based on the World System Model, whereby the relative scoring of potential impact is represented by the relative size of the circle representing that particular node of the model. These size gradations relate to the colour coding in the original impact matrix, as shown below in Figure 2.4

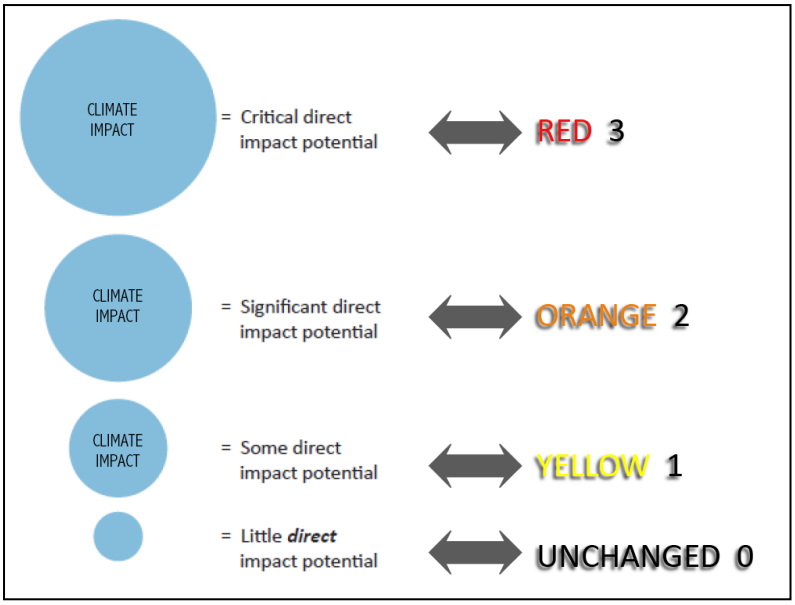


Figure *2.4 – Correlations of Direct Impact Pattern diagram symbols with the coding of the Impact Matrix Table 2.1*

This allows for an 'at a glance' sense of the potential climate impact pattern for any region and for easy comparison between regions. A sample impact pattern to illustrate the method is shown in Figure 2.5.

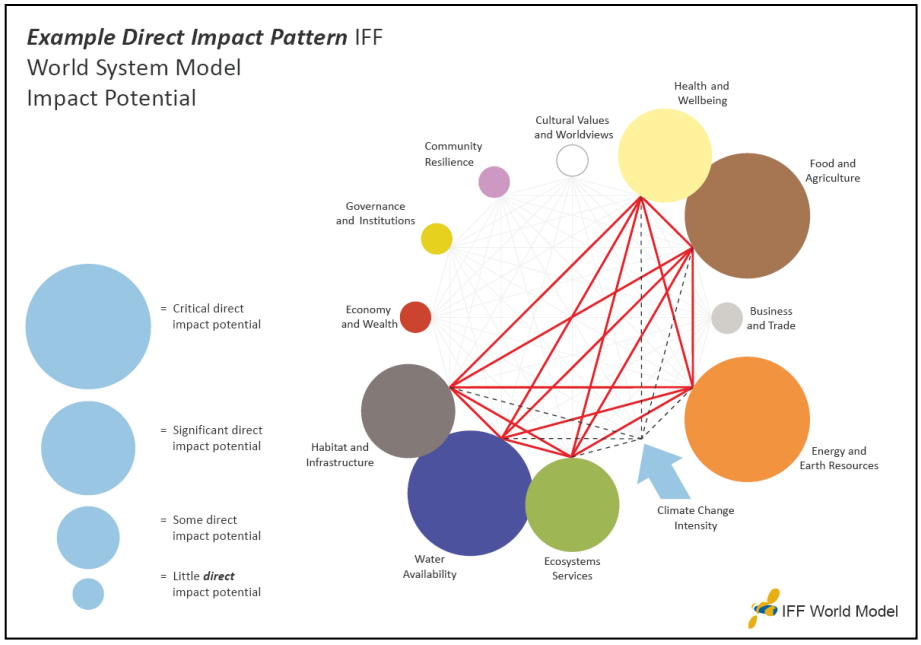
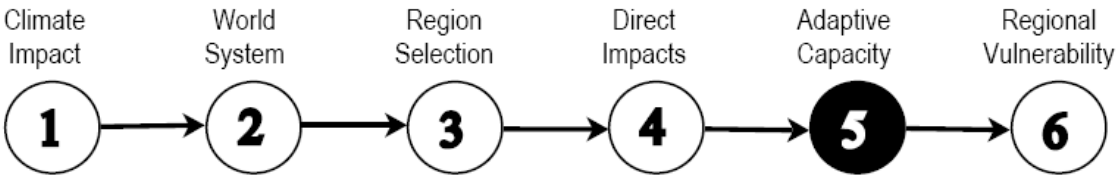


Figure 2.5 – Example of the application of the impact scaling to the IFF World System model to generate the Direct Impact Pattern.

This graphic representation (systems map) of the Direct Impact Pattern communicates various aspects of the potential climate impact for that region or country. It shows which nodes appear to be sensitive to climate change and to what extent. It also shows the possible interconnections between these sensitivities as red lines. These highlighted lines represent the complex of paired interactions that are could arise (each of which is explored in detail in the county and region analyses in Book 2 Section 1). Climate impact is unlikely to be restricted to one node in isolation but will act both in parallel and in mutual interaction or knock-on effects.

2.5 Assessment of Regional Adaptive Capacity



The initial systems mapping identifies potential direct impacts of climate change on different regions with differing sensitivity to those impacts represented by the different sizes of circle. However, the overall impact on a country or region also depends on that area's *adaptive capacity* and *societal resilience* – in other words its capacity to absorb the change and still go on functioning as a social environment system.

The adaptive capacity of a society is a complex function which involves originally excluded nodes in the World System Model (see Figure 1.3., namely:

- *Governance and Institutions* determining capability of response,
- *Cultural Worldviews* determining dominant priorities in society
- *Economy and Wealth* determining economic strength and dynamism
- *Business and Trade* determining enterprise and markets

'Adaptive capacity' is not therefore solely about the capacity to respond or adapt to climate change. It is also a general measure of resilience or adaptability in the face of *all* unexpected or unwelcome impacts on a region. Climate change is one such threat, rarely the main one, and so is seen by security experts as a 'threat multiplier'. This means that risks that exist under usual conditions are amplified by the added impact of climate change, placing an even greater strain on a country or region's adaptive capacity (CAN Corporation 2007).

Hence in considering the potential impacts on the UK of climate change impacts elsewhere in the world, a critical consideration must be the capacity of existing systems to absorb or otherwise cope with potential direct climate change impacts and how far these impacts will exacerbate existing vulnerabilities.

From the literature review of hundreds of reports and papers it seems that assessment of the 'impact of impacts' – social, economic, psychological, political etc – is very little studied compared to direct impact. By contrast, assessing the potential responses of a human system to climatic impact in practice is too complex a task to be modeled in the same manner as climate change. It is also worth noting that assessing primary impacts is the domain of climate scientists whereas assessing the adaptive response capacity falls to specialists in multiple disciplines, whose contributions are distributed in pockets around the world in a field that is very early in its development.

The Ministry of Defence's recent report on Global Strategic Trends to 2040 likewise makes a direct connection between climate stress and consequential economic, social and political impacts in 'weak' states that lack the capacity to cope:

"Weak states have limited capacity for governance and many are unlikely to adapt to the environmental challenges of climate change…. They often have poor human rights records and suffer endemic corruption which weakens

governance and service provision, increasing the likelihood of recurring instability. As the severity and incidence of internal instability increases, exacerbated by climate change, long-term societal changes can occur, such as the creation of large numbers of orphaned children or the displacement of large ethnic or tribal groups." (MOD 2010)

Thus the critical missing piece of the jigsaw for assessing the 'impact of impacts' is some measure of a country or region's adaptive capacity and societal resilience. What indicators will measure the difference between a 'weak' state, to use the MOD phrase, and a 'strong' state, a fragile region and a resilient one? A number of international research projects around the world are in the early stages of addressing this complex problem (UN Framework 2004).

The Potsdam Institute for Climate Impact Research has an elaborate model for generic adaptive capacity, specifically related to 'the ability to implement planned adaptation measures' in response to climate change (Schroeter 2004). This is a good model, although data are short and so a selection of proxy measures for larger concepts such as 'flexibility' or 'ability' is inevitably required. Whilst the index may give an approximate measure of capacity, it does not pay explicit attention to the ability to put it to use in crisis conditions.

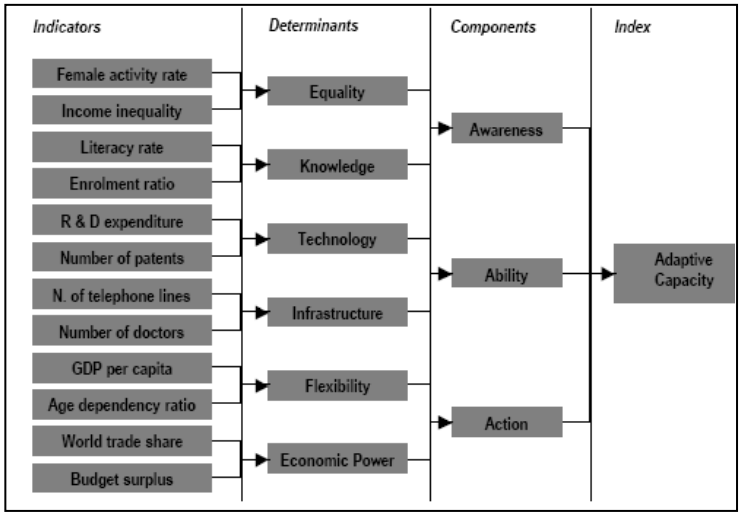


Figure 2.6 A structure *for determining adaptive capacity (Potsdam Institute for Climate Impact Research (Schroeter 2004)*

Another of the factors universally identified as critical in managing shocks to any system is governance capacity. Robert Dorff (2008) of the US Strategic Studies Institute expresses a now commonly held view, not just in the US, when he says:

"A US Grand Strategy (encompassing our national security strategy) should have, as its core objective, the promotion and sustainment of effective legitimate governance and the market economies underlying them…..To the extent that we can integrate global climate change response, consequence management, and mitigation capacity building as components of promoting and sustaining effective legitimate governance, we have a very useful convergence."

Thus, alongside the indicators listed above, indices of effective governance are another essential component of any ranking of adaptive capacity.

A most thorough and recent consideration of such issues is a technical report published by the Tyndall Centre investigating 'New indicators of vulnerability and adaptive capacity' (Adger et al 2004). That report reviews some of the difficulties in developing an index – not least the absence of data, and the fact that generic measures of vulnerability for countries and regions can miss highly specific local vulnerabilities or sources of resilience. The report finds that indicators of health, education and governance are most closely correlated with resilience. And it suggests that the best way to construct a 'vulnerability index' for different countries and regions is to assign each country to categories (say 1 to 5) against a range of relevant proxy indicators for resilience and adaptive capacity (with a concentration on health, education and governance) and then to sum these together to provide an overall ranking of vulnerability. The sorting into categories allows for comparison between countries without assuming a greater level of precision than the actual country data can bear.

This is the approach adopted in this report. An overall measure of adaptive capacity was assembled from measures of *Worldwide Governance Indicators* (World Bank Group 2009), the health, education and general quality of the human resource available as measured by the *UN Human Development Indicators* (UNPD 2010); and the overall proxy measure of adaptive capacity provided by the *Failed States Index* compiled each year by Foreign Policy and The Fund for Peace (2010). These are also a) comprehensive indices which will allow for global comparisons and b) kept up to date to allow for updating the vulnerability index over time.

The Failed States Index uses 12 indicators of 'state cohesion and performance' compiled from more than 30,000 publicly available sources to arrive at a ranking for 177 states in the world. The 12 indicators are:

Social Indicators

- Mounting Demographic Pressures
- Massive Movement of Refugees or Internally Displaced Persons creating Complex Humanitarian Emergencies
- Legacy of Vengeance-Seeking Group Grievance or Group Paranoia
- Chronic and Sustained Human Flight

Economic Indicators

- Uneven Economic Development along Group Lines
- Sharp and/or Severe Economic Decline

Political Indicators

- Criminalisation and/or Delegitimisation of the State
- Progressive Deterioration of Public Services
- Suspension or Arbitrary Application of the Rule of Law and Widespread Violation of Human Rights
- Security Apparatus Operates as a "State Within a State"
- Rise of Factionalized Elites
- Intervention of Other States or External Political Actors

The Failed States Index grades countries into five categories: critical, in danger, borderline, stable, most stable. These categories might be taken to read across directly into capacity to absorb the impact of climate change as a threat multiplier.

The World Bank's Worldwide Governance Indicators give a useful counter-check, particularly the country indicators for 'government effectiveness' and 'political stability' which are the measures used for this study (available in a time series going back to 1996). The World Bank (2009) ranks countries against these indicators into six bands based on percentiles: 0–10; 10-25; 25-50; 50-75; 75-90; 90-100.

The UN Human Development Index (UNDP 2010) provides a good proxy for the quality, health and education of the human resource to set alongside the quality of governance and institutions. The HDI allocates countries to four simple bands: low, medium, high and very high human development.

For each country/region in question adaptive capacity has been estimated in the following way: rankings from the Failed States Index, the World Bank Governance Indicators for political stability and government effectiveness, and the Human Development Index have been compiled. The grading in each category was assigned a number **n :** 1 – 5 for Failed States, 1 – 6 for Political Stability and Governance Effectiveness respectively, and 1 - 4 for the Human Development Index. Each figure was then normalized (as a fraction of 1) and the elements summed to give an index figure **x**. The framework is summarized in Table 2.2

Proxy Indicator (selected for contribution to adaptive capacity)	**Country or Region Grading Scale (as per that system)**	
Failed States Index	Grading 1 to 5	n /5=x
Political Stability	Grading 1 to 6	n/6=x
Governance Effectiveness	Grading 1 to 6	n/6=x
Human Development Index	Grading 1 to 4	n/4=x

Table 2.2 – Proxy Indicators for Adaptive Capacity and Grading Scale

The sum of these measures (multiplied by 10 for ease of comparison) is taken as a single indicator of adaptive capacity for any country, and the average over the principal countries in a region provides a single indicator for that region. The country-level detail used to calculate the regional level indicator is also given and can usefully identify specific pockets of instability or resilience within a region. It should be noted that unforeseen geo-political changes could shift the indicators used below.

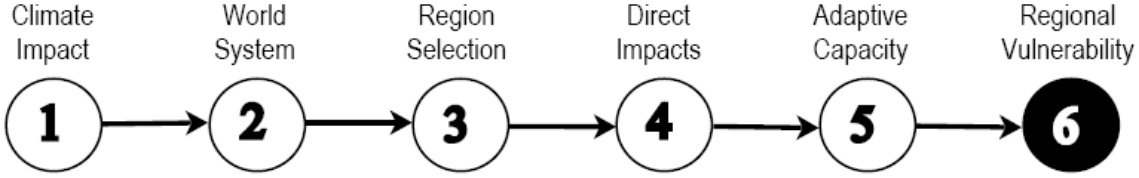
These assessment measures (which can be found at the end of each Country World Story in Book 2 Section 1) were divided into three bands indicating the adaptive capacity and societal resilience of specific countries and regions in an overall index of adaptive capacity, colour coded as in Table 2.3

1	Indicator values 0 to 18	Fragile adaptive capacity
2	Indicator values 19 to 30	Weak adaptive capacity
3	Indicator values 30 upwards	Reasonable adaptive capacity

Table 2.3 Classification grading of Adaptive Capacity using data from the analysis at the conclusion of each World Story in Book 2 Section 1.

These numbers can then be combined with climate impact sensitivity to generate an overall ranking of vulnerability. This is explained in Section 2.6 which follows.

2.6 Mapping Regional Vulnerability



The final step involves combining assessments of direct impact of climate change on a country or region with its perceived capacity to adapt to the impact. The combination is partly based on the pioneering work of Schroter (2004) and Metzger in their European study. A combination of direct impact and level of adaptive capacity provides a measure of overall vulnerability. A summary of their method is shown in Figure 2.7.

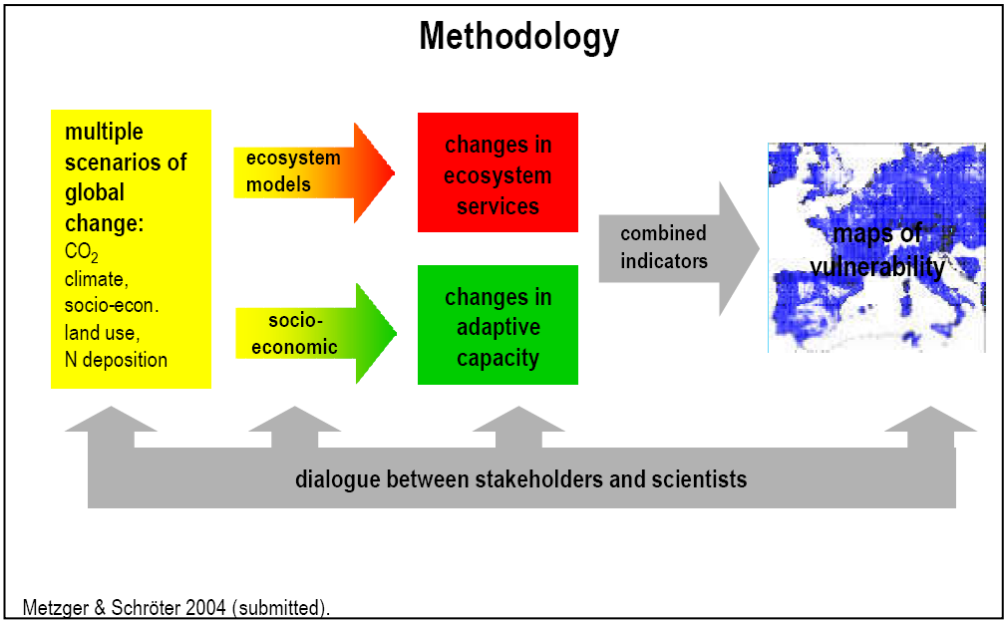


Figure 2.7 – Example of a vulnerability method used *for Europe*

For the purposes of this study, a measure of the overall vulnerability of a country or region is arrived at by dividing the impact *sensitivity* by the *adaptive capacity* rating (1=low; 3=high) to give its *vulnerability*. The overall result is divided by 2 to bring the numbers within a ten point scale for easy reference.

The calculation is represented by the equation:

Climate Sensitivity Index	÷	Adaptive Capacity Rating	=	Relative Overall Vulnerability

Thus a country very sensitive to climate change will score higher in terms of vulnerability if it has low adaptive capacity.

The calculation is indicative rather than definitive. The process offers a way to arrive at an informed estimate of relative overall vulnerability and hence provides a means of identifying which areas of the world have the greatest vulnerability to climate change in terms of their ability to sustain basic functions in the face of moderate to severe climate change impacts. The ability to function is a resultant of climate impact sensitivity and local adaptive capacity.

Table 2.4 sets out the result of this calculation arranged in ascending order of climate sensitivity.

COUNTRY OR REGION	Ranking total as CLIMATE SENSITIVITY INDEX	ADAPTIVE CAPACITY RATING	RELATIVE OVERALL VULNERABILITY
MidAfrica	17	1	17.0
Indian SubContinent	16	1	16.0
Middle East	15	2	7.5
Central America & Caribbean	13	2	6.5
SE Asia	12	2	6.0
China	12	2	6.0
South Africa	12	2	6.0
Brazil	12	2	6.0
North Africa	12	2	6.0
Central & Eastern Europe	12	2	6.0
Western Europe	10	3	3.3
Andean S America	10	2	5.0
USA	10	3	3.3
Australia	9	3	3.0
Canada	7	3	2.3
New Zealand	5	3	1.7
Russia	3	2	1.5

Table 2.4 Establishing relative overall vulnerability to climate change

In Table 2.4 the final column, *Relative Overall Vulnerability* establishes an approximate ranking of vulnerability to the risk that functionality will be disrupted if climate change impacts unfold towards the high end of climate change impact scenarios. In the following Table 2.5 the sequence of countries

and regions is rearranged according to ascending vulnerability and the triage performed using the colour code shown in the following key. This ranking now enables a simple triage to establish three levels.

Triage Key of Vulnerability		
	11 to 21	Due to high vulnerability consequences of climate change impact could be extreme
	6 to 10	Due to moderate vulnerability consequences of climate change impact could be severe
	1 to 5	Due lower vulnerability consequences of climate change likely to be absorbed

Table 2.5 – Triage coding of relative consequences of degrees of vulnerability

The results show, out of the seventeen countries or regions, there are two regions that can be considered to be highly vulnerable, eight regions moderate vulnerable, and seven regions of lower vulnerability.

VULNER-ABILITY RANKING	Region and Country Vulnerability Triage	RELATIVE OVERALL VULNER-ABILITY
1	Mid-Africa	17.0
2	Indian Sub-Continent	16.0
3	Middle East	7.5
4	Central America & Caribbean	6.5
5	SE Asia	6.0
6	China	6.0
7	South Africa	6.0
8	Brazil	6.0
9	North Africa	6.0
10	Central & Eastern Europe	6.0
11	Andean S America	5.0
12	Western Europe	3.3
13	United States	3.3
14	Australia	3.0
15	Canada	2.3
16	New Zealand	1.7
17	Russia	1.5

Table 2.6 Triage of climate impact vulnerability

The vulnerability ratings, summarised in the map in Figure 2.8, provide a basis for considering in Section 4 the potential impact on the UK of climate change impacts in these regions and countries.

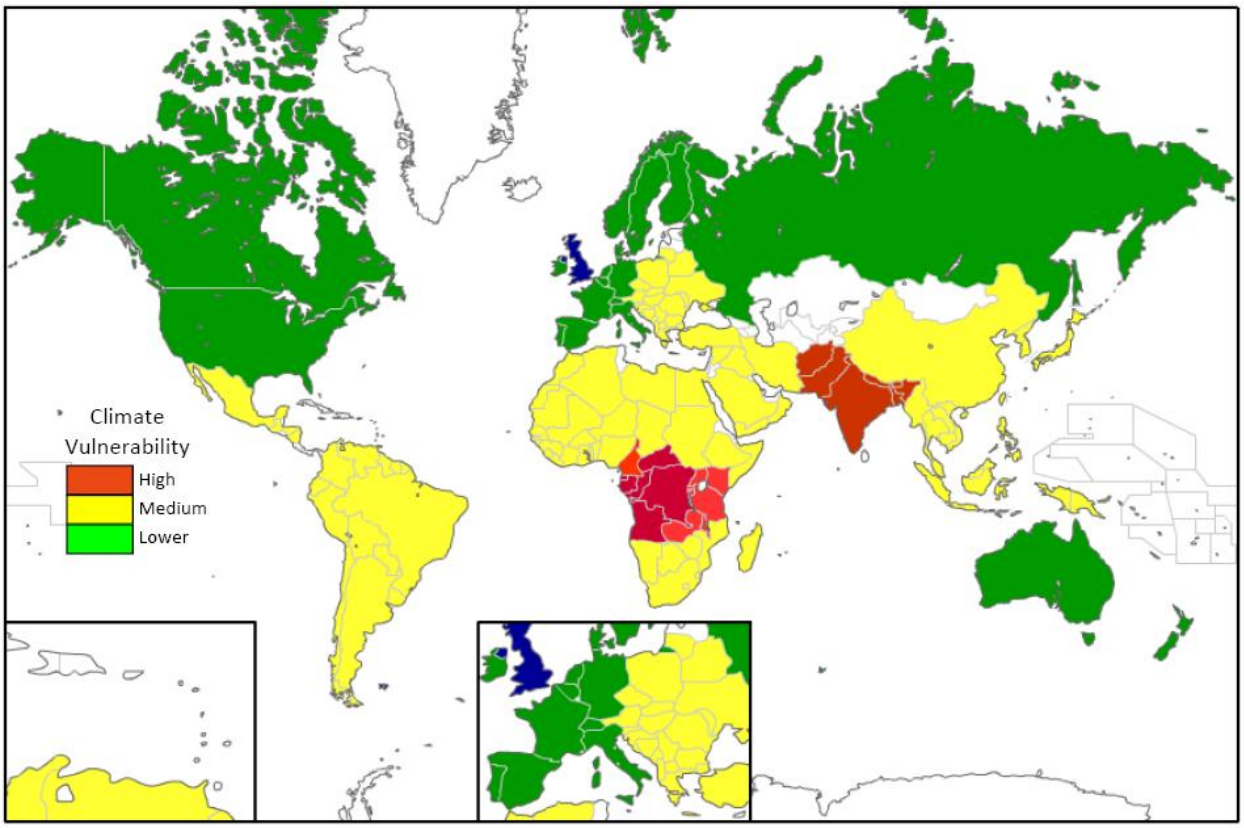


Figure 2.8 – World map showing the distribution high, medium and lower vulnerability countries and regions in relation to climate change impact.

Please note that at this stage in the process *the ranking does **not** indicate the potential impact on the UK**.*** This requires the further steps in the methodology of ascertaining the nature and extent of interdependency or interest that the UK has in any region. For example, a highly vulnerable area may have little relationship to the UK and have less priority than a moderately vulnerable area with a relationship of high interconnection and interdependence with the UK. This next layer of analysis will be dealt with in Section 4.

SECTION 3 Climate Impact Mapping – Direct Impact Patterns

Introduction

This section introduces a system mapping technique to be referred to as 'Direct Impact Pattern'. It is based on the World System Model as shown in Figure 1.2 (p.5) with the additional representation of estimated scale of impact as shown in Figure 2.5 (p.25). The information base for this representation is taken from Table 2.1 (p.24).

The use of this mapping technique gives the reader a summary "snapshot" or "fingerprint" assessment of the reviewed literature of climate change impact on each country/region. By reviewing and comparing these system maps the reader can quickly identify the key impacts for each country or region. These system maps summarise estimation of impact on relevant nodes based on the reviewed literature. They indicate the extent to which the literature indicated the seriousness of climate change impact on relevant nodes for that country or region. This is referred to here as 1st Order Impact.

In Book 2 Section One a more detailed mapping uses the same 'fingerprints' with the added analysis of the interconnections between impacted nodes, referred to as 2nd Order Impacts. The 2nd Order System Maps are accompanied by extensive quotations from the literature which are also referenced in Book 1 Section 6 – References.

The Direct Impact Patterns give a perspective on which of the seven primary nodes as a selected in Figure 1.3 (p.10) are impacted and to what extent, as described in the literature, namely :

- Health and Wellbeing
- Food and Agriculture
- Energy and Earth resources
- Ecosystem Services
- Water Availability
- Habitat and Infrastructure
- Community Resilience

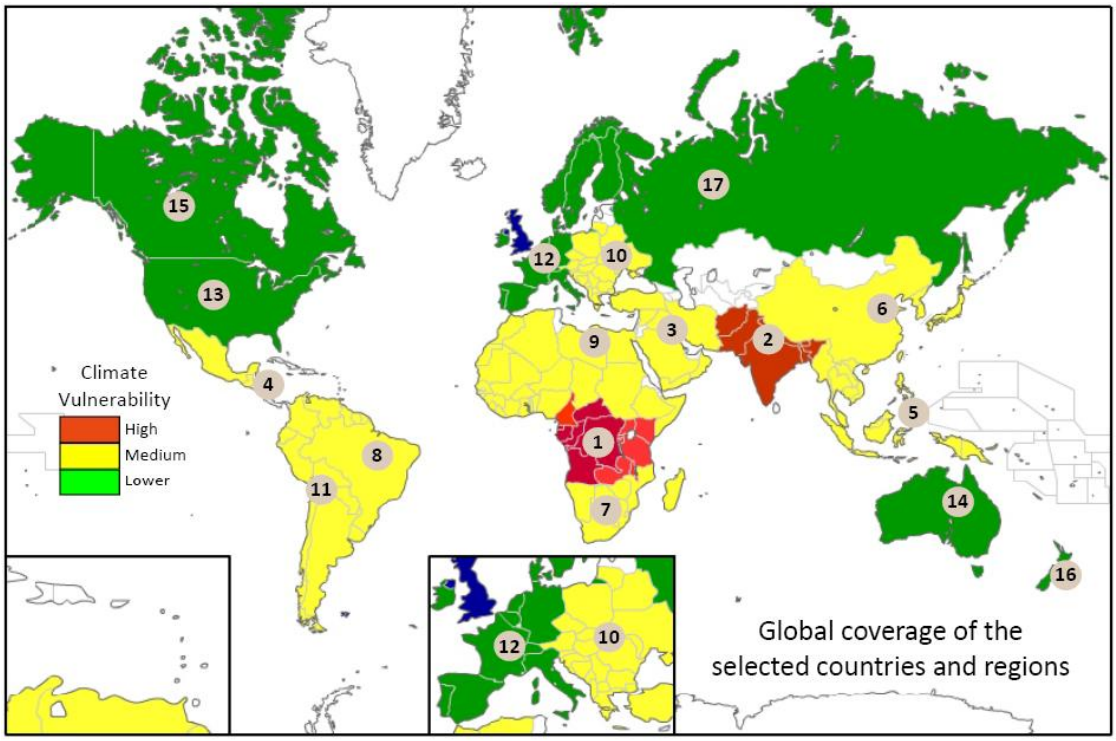
.Each node is scaled using the method described in Figure 2.4 (p.25) which takes the information in Table 2.1 (p.24) and transfers to the system maps as illustrated in Figure 2.5 (p.25).

The 2nd Order Direct Impact Patterns, referred to as 'World Stories', make up Book2 Section 1. These take the 'fingerprint' further and systematically explore paired connections between impacted nodes within each country/region. These more detailed explorations are based on the proposition that direct impacts in the real world rarely happen in isolation: for example, water availability and energy production, and ecosystem services and agriculture are clearly in systemic relationships, for example.

Each Direct Impact Pattern system map is accompanied by a table showing

- Climate Sensitivity Position – the relative sensitivity to direct climate impact as calculated in Section 2.6 Table 2.4 page 34.
- Adaptive Capacity Rating – the level of adaptive capacity based on the proxy calculations as assessed section 2.5, and reported in more detail in Book 1 Section 1.
- Overall Vulnerability as calculated by the equation in Section 2.6 on page 33

Selected Regions and Countries According to Vulnerability



1	Mid-Africa	10	Central and Eastern Europe
2	Indian Sub-Continent	11	Andean South America
3	Middle East	12	Western Europe
4	Central America and Caribbean	13	United States
5	SE Asia	14	Australia
6	China	15	Canada
7	Southern Africa	16	New Zealand
8	Brazil	17	Russia
9	North Africa	18	UK Overseas Territories (UKOT) (♣)

♣ The UKOT are not prioritised for vulnerability – see Section 3.18

Figure 3.1 Map showing the distribution of countries and regions analysed in relation to the geography of climate impact vulnerability as calculated in Table 2.6 (p.35).

The system maps of counties and regions that follow are arranged in a sequence from highest to lowest vulnerability.

3.1 Mid-Africa Direct Impact Pattern

Mid Africa is the region of Africa which runs approximately from Cameroon and Angola in the west to Kenya and Tanzania in the east. It excludes North Africa and the southern fringe of the Sahel and also excludes Southern Africa which is treated separately.

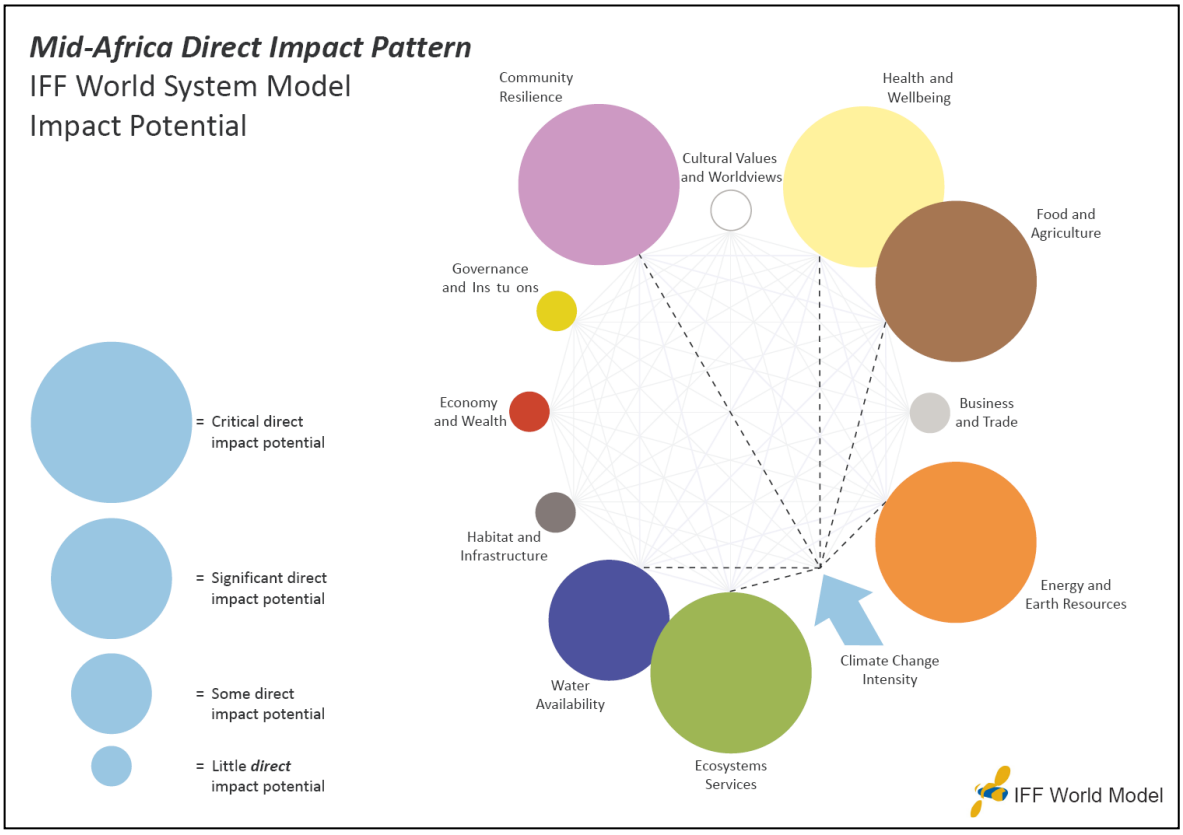


Figure 3.1.1 System Map showing the Mid-Africa Direct Impact Pattern of climate change

Climate Sensitivity Position	1 out of 17	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*LOW*	*Reference Book 1 Section 1 (p.23)*
Overall Vulnerability	*HIGH*	*Reference Table 2.6 (p35)*

Table 3.1.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Mid-Africa

3.2 Indian Subcontinent Direct Impact Pattern

The Indian Subcontinent includes India, Pakistan, Bangladesh, Nepal, Bhutan and Sri Lanka

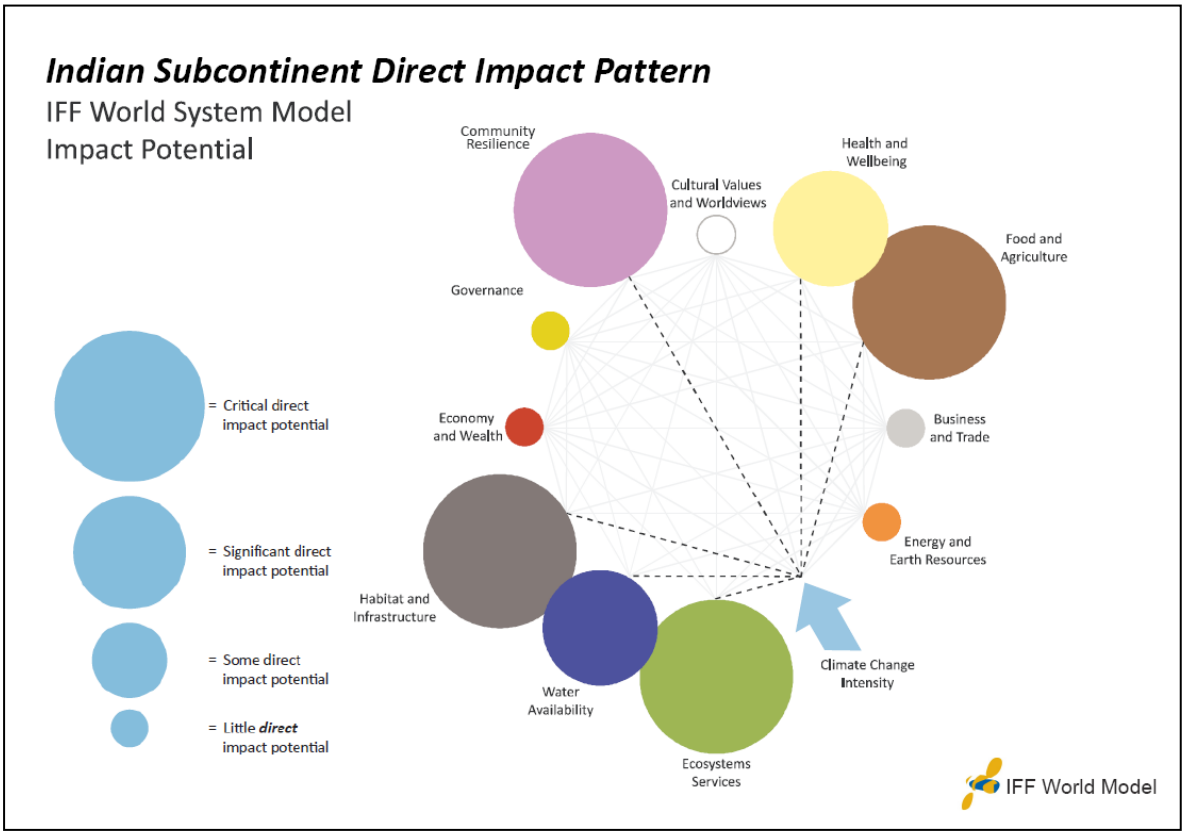


Figure 3.2.1 System Map showing the Indian Subcontinent Direct Impact Pattern of climate change

Climate Sensitivity Position	*3 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*LOW*	*Reference Book 1 Section 1 (p.40)*
Overall Vulnerability	*HIGH*	*Reference Table 2.6 (p35)*

Table 3.2.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Indian Subcontinent

3.3 Middle East Direct Climate Impact Pattern

The Middle East includes Saudi Arabia, Yemen, Oman, UAE, Iraq, Syria, Jordan, Iran, Qatar and Kuwait.

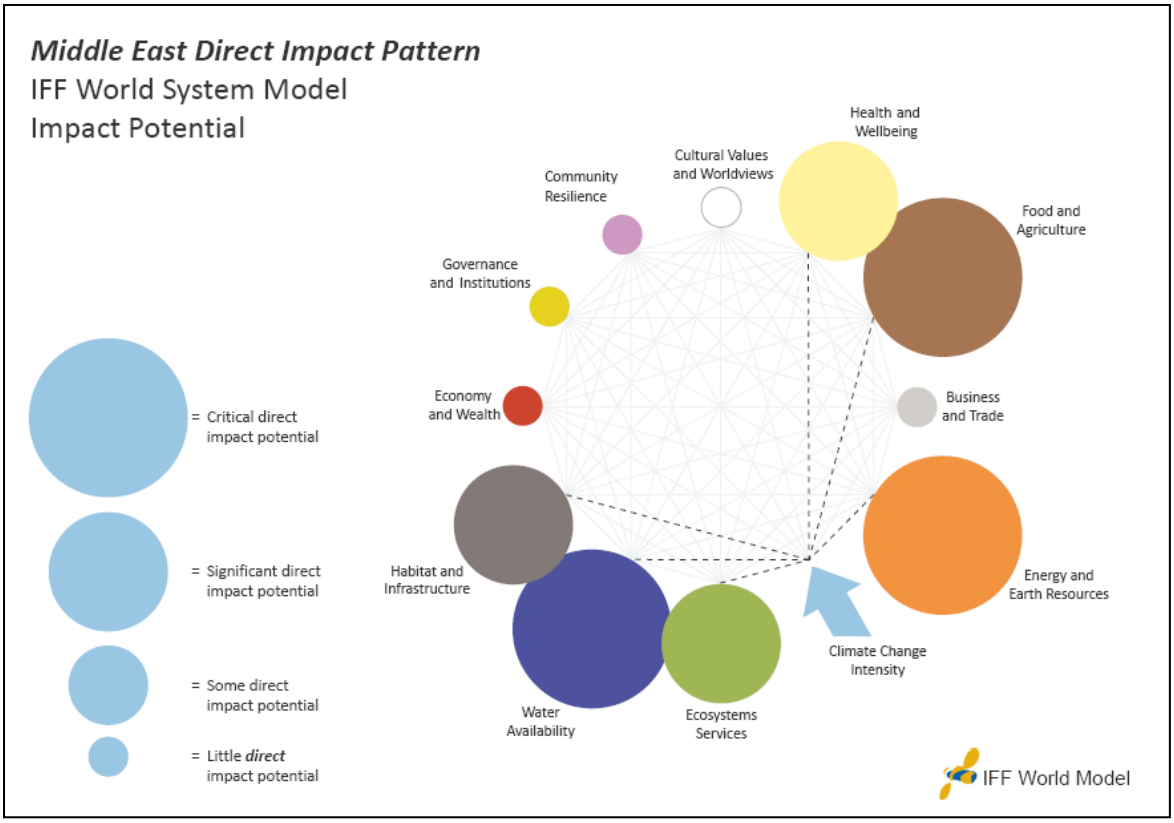


Figure 3.3.1 System Map showing the Middle East Direct Impact Pattern of climate change

Climate Sensitivity Position	*2 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.51)*
Overall Vulnerability	*HIGH*	*Reference Table 2.6 (p35)*

Table 3.3.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Middle East

3.4 Central America & Caribbean Direct Impact Pattern

Central America and Caribbean includes Mexico, Cuba, Haiti, Costa Rica, Nicaragua, Honduras, Panama and Guatemala. The Caribbean region also includes various British Overseas Territories, namely Anguilla, the British Virgin Islands, the Cayman Islands, Montserrat, and the Turks & Caicos Islands. This gives this section particular significance from a UK Overseas Territories perspective.

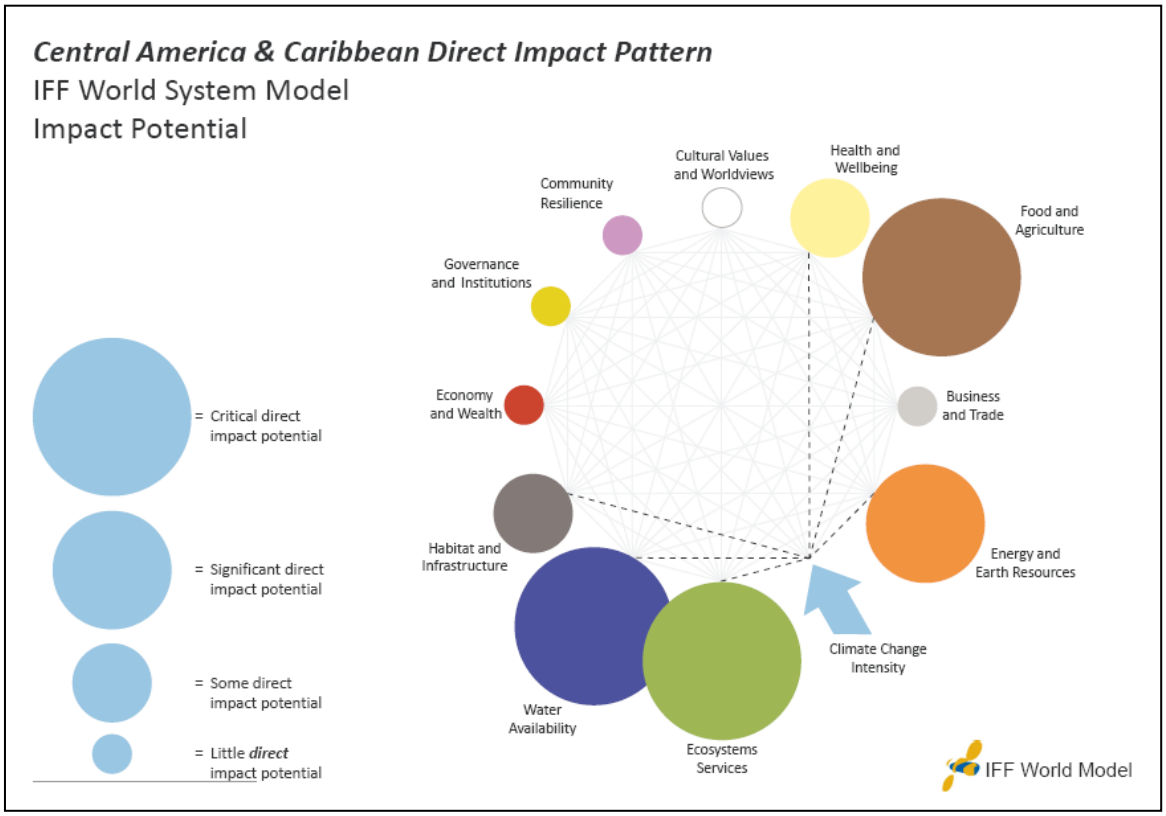


Figure 3.4.1 System Map showing the Central American and Caribbean Direct Impact Pattern of climate change

Climate Sensitivity Position	*4 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*LOW*	*Reference Book 1 Section 1 (p.65)*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.4.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Central American and Caribbean

3.5 South East Asia Direct Impact Pattern

South East Asia includes Thailand, Cambodia, Vietnam, Laos, Myanmar, Malaysia, Indonesia, Japan, S Korea, N Korea and the Philippines.

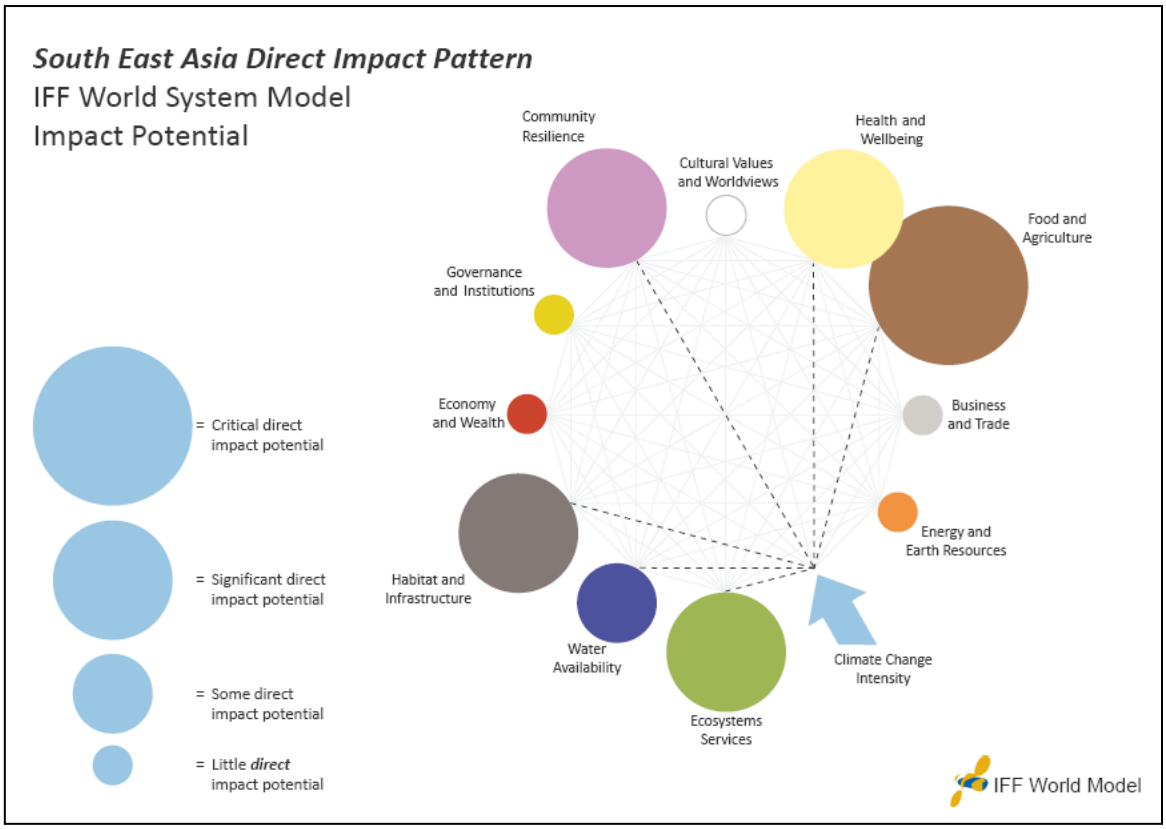


Figure 3.5.1 System Map showing the South East Asia Direct Impact Pattern of climate change

Climate Sensitivity Position	*5 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.76)*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.5.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for South East Asia

3.6 China Direct Impact Pattern

China is treated alone.

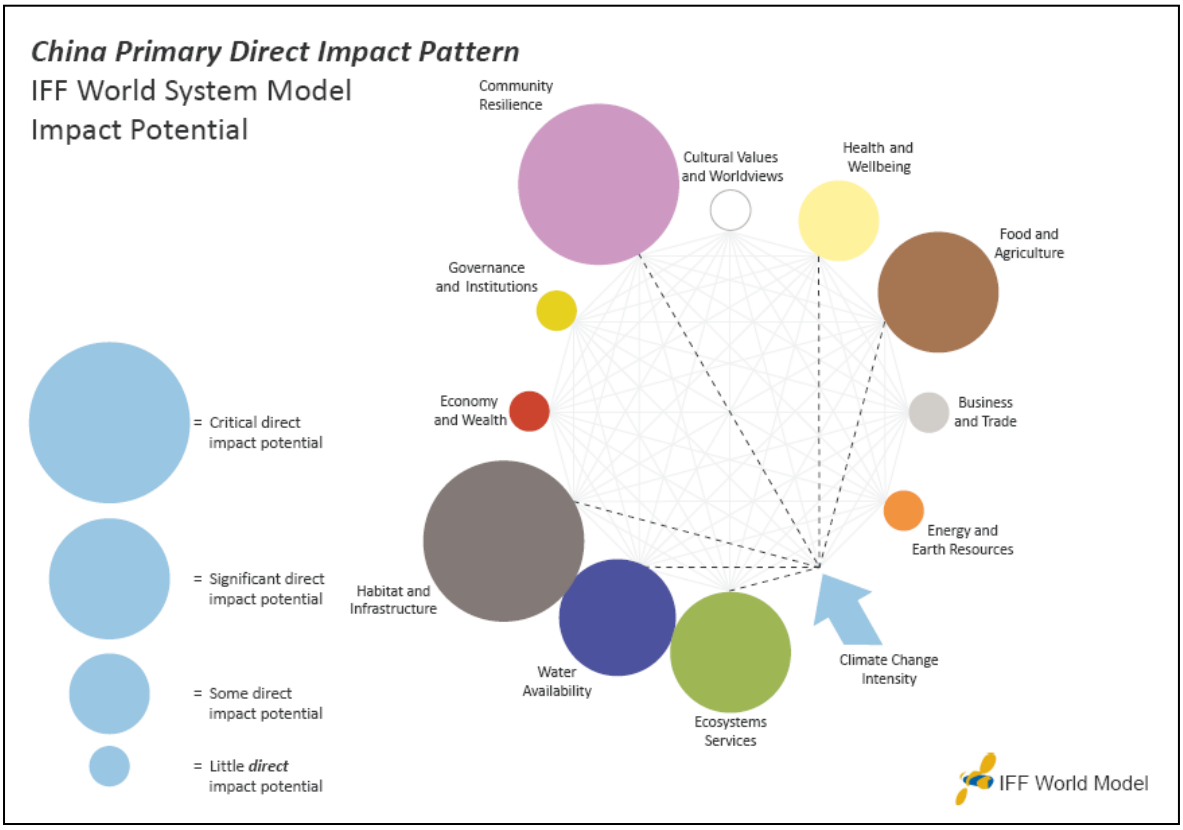


Figure 3.6.1 System Map showing the China Direct Impact Pattern of climate change

Climate Sensitivity Position	*6 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.91).*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.6.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for China

3.7 Southern Africa Direct Impact Pattern

Southern Africa includes South Africa, Namibia, Botswana, Zimbabwe and Mozambique.

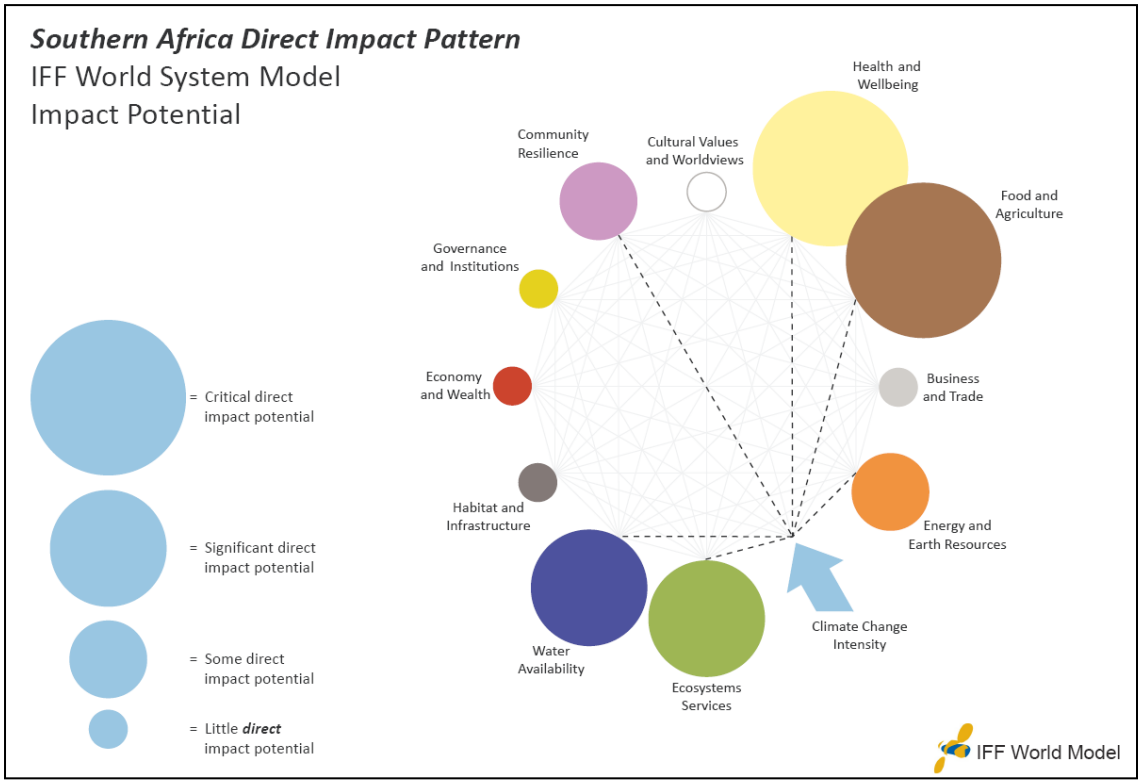


Figure 3.7.1 System Map showing the Southern Africa Direct Impact Pattern of climate change

Climate Sensitivity Position	*7 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.109)*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.7.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Southern Africa

3.8 Brazil Direct Impact Pattern

Brazil is treated alone.

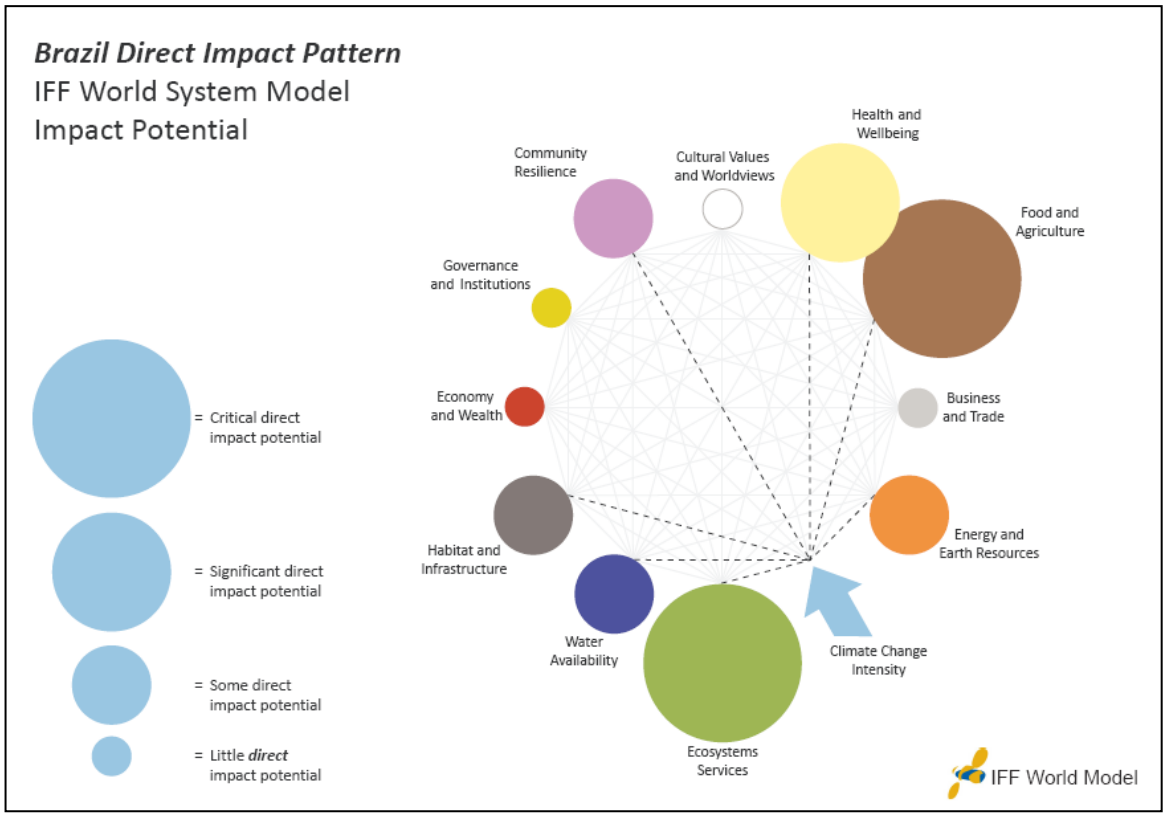


Figure 3.8.1 System Map showing the Brazil Direct Impact Pattern of climate change

Climate Sensitivity Position	*8 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.121)*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.8.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Brazil

3.9 North Africa Direct Impact Pattern

North Africa includes Egypt, Libya, Tunisia, Morocco, Algeria, Niger, Mali and Mauritania.

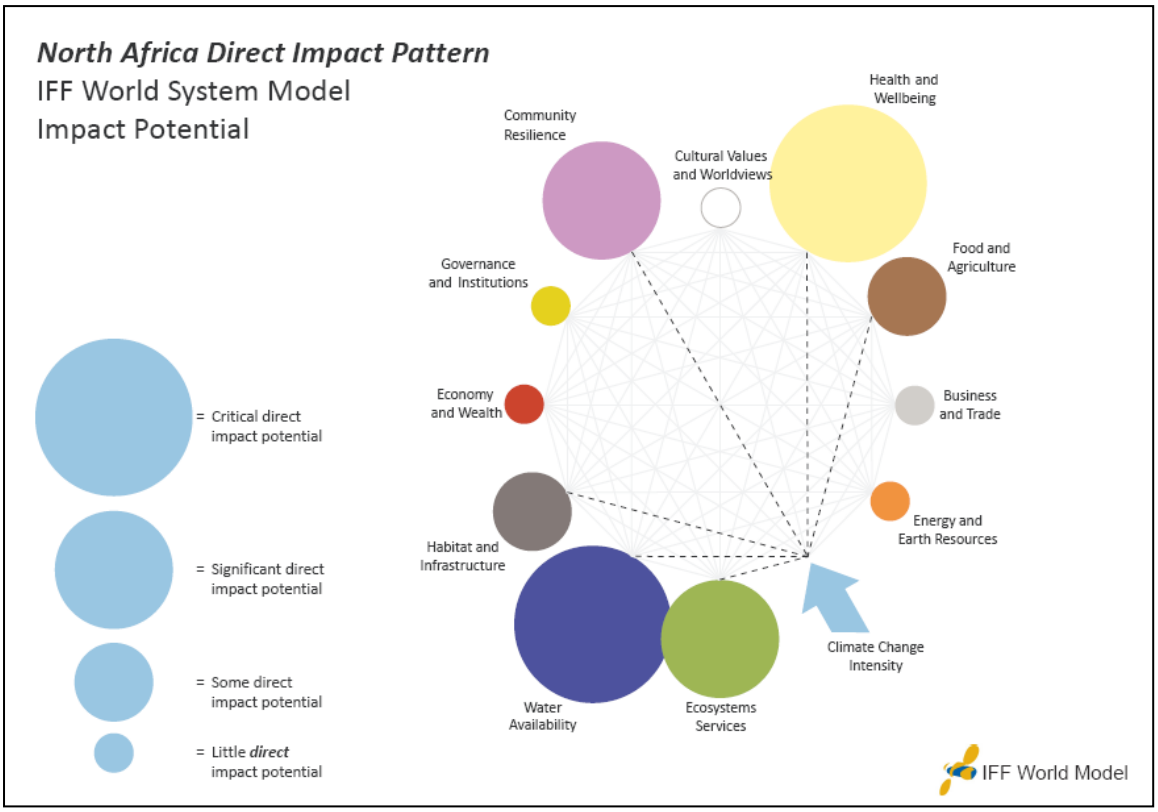


Figure 3.9.1 System Map showing the North Africa Direct Impact Pattern of climate change

Climate Sensitivity Position	*9 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.133)*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.9.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for North Africa

3.10 Central & Eastern Europe Direct Impact Pattern

Central and Eastern Europe includes Romania, Hungary, the Czech Republic, Slovakia, Poland, Bosnia, Serbia, Croatia and Bulgaria.

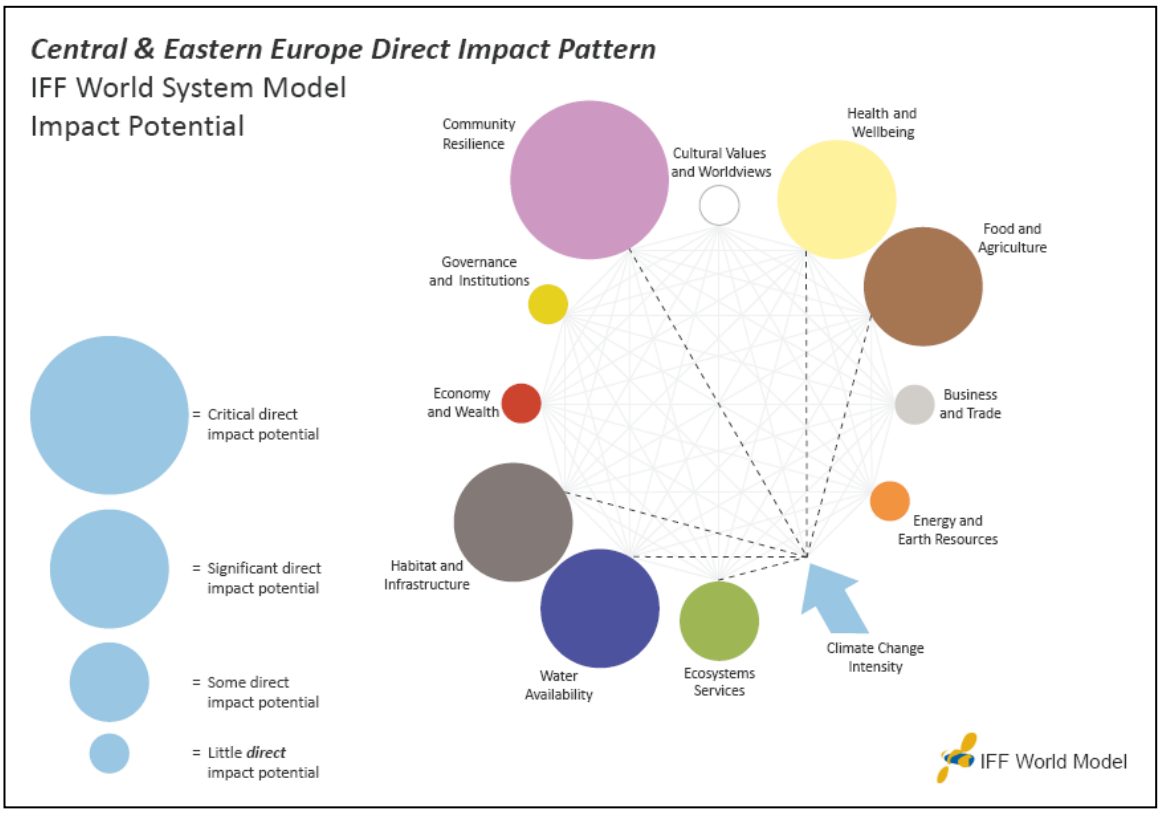


Figure 3.10.1 System Map showing the Central and Eastern Europe Direct Impact Pattern of climate change

Climate Sensitivity Position	*10 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.144)*
Overall Vulnerability	*MEDIUM*	*Reference Table 2.6 (p35)*

Table 3.10.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Central and Eastern Europe

3.11 Andean South America Direct Impact Pattern

Andean South America includes Peru, Bolivia, Ecuador, Venezuela, Argentina, Chile and Colombia.

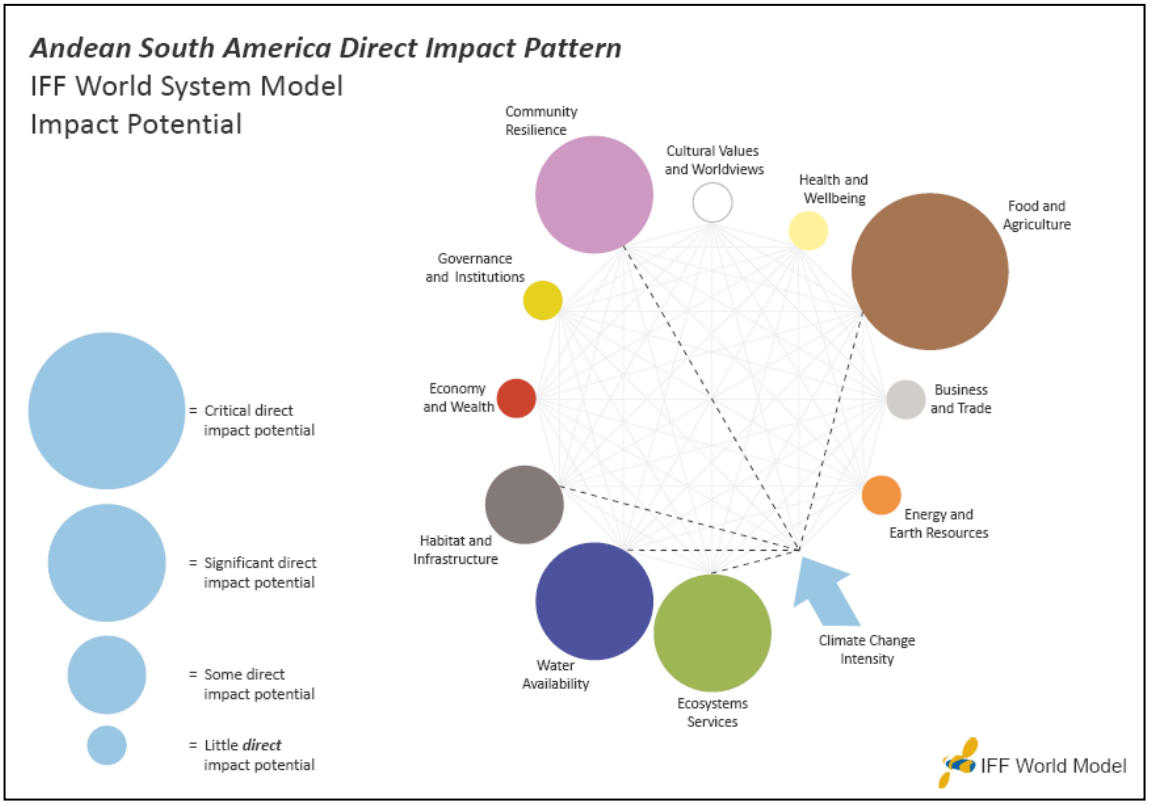


Figure 3.11.1 System Map showing the Andean South America Direct Impact Pattern of climate change

Climate Sensitivity Position	*11 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (p.156)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.11.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Andean South America

3.12 Western Europe Direct Impact Pattern

Western Europe includes Portugal, Spain, Italy, Greece, France, Austria, Belgium, The Netherlands, Germany, Ireland, (the UK), Norway, Denmark, Sweden, Finland, Estonia, Latvia, and Lithuania.

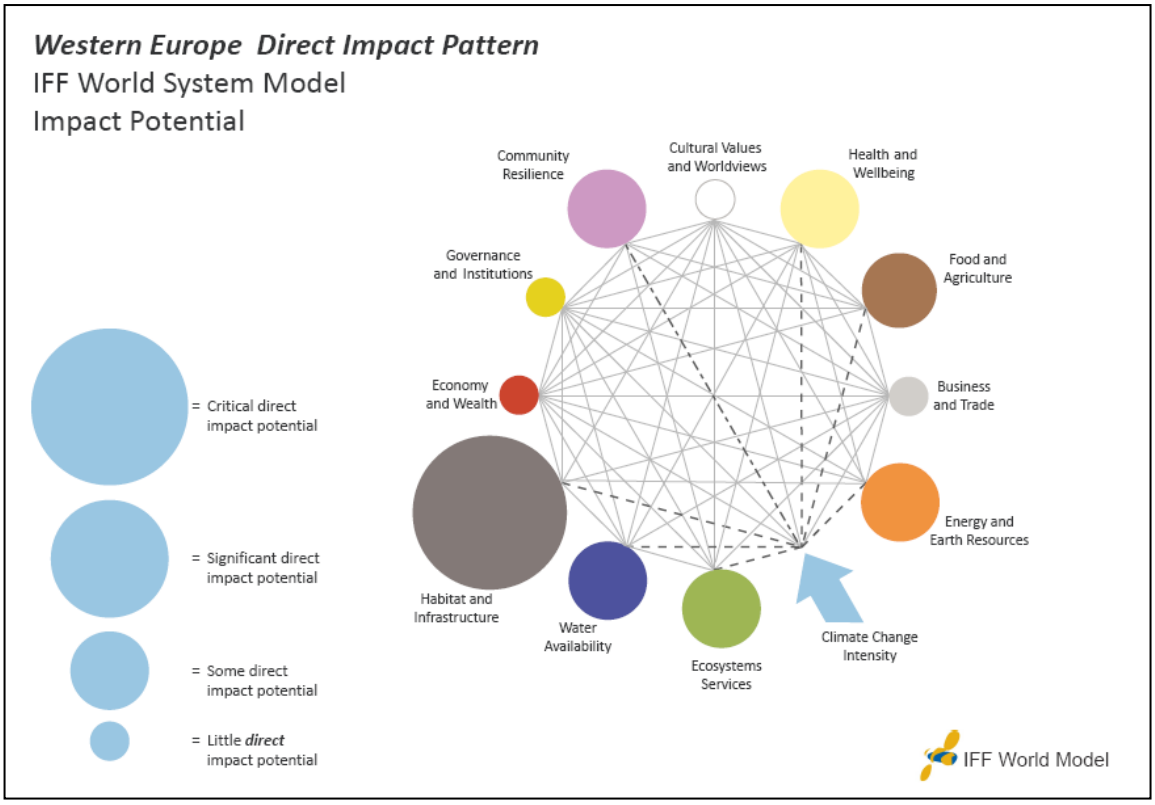


Figure 3.12.1 System Map showing the Western Europe Direct Impact Pattern of climate change

Climate Sensitivity Position	*12 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*HIGH*	*Reference Book 1 Section 1 (p.171)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.12.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Western Europe

3.13 United States Direct Impact Pattern

The United States constitutes the contiguous states of the mainland US and the states of Alaska and Hawaii.

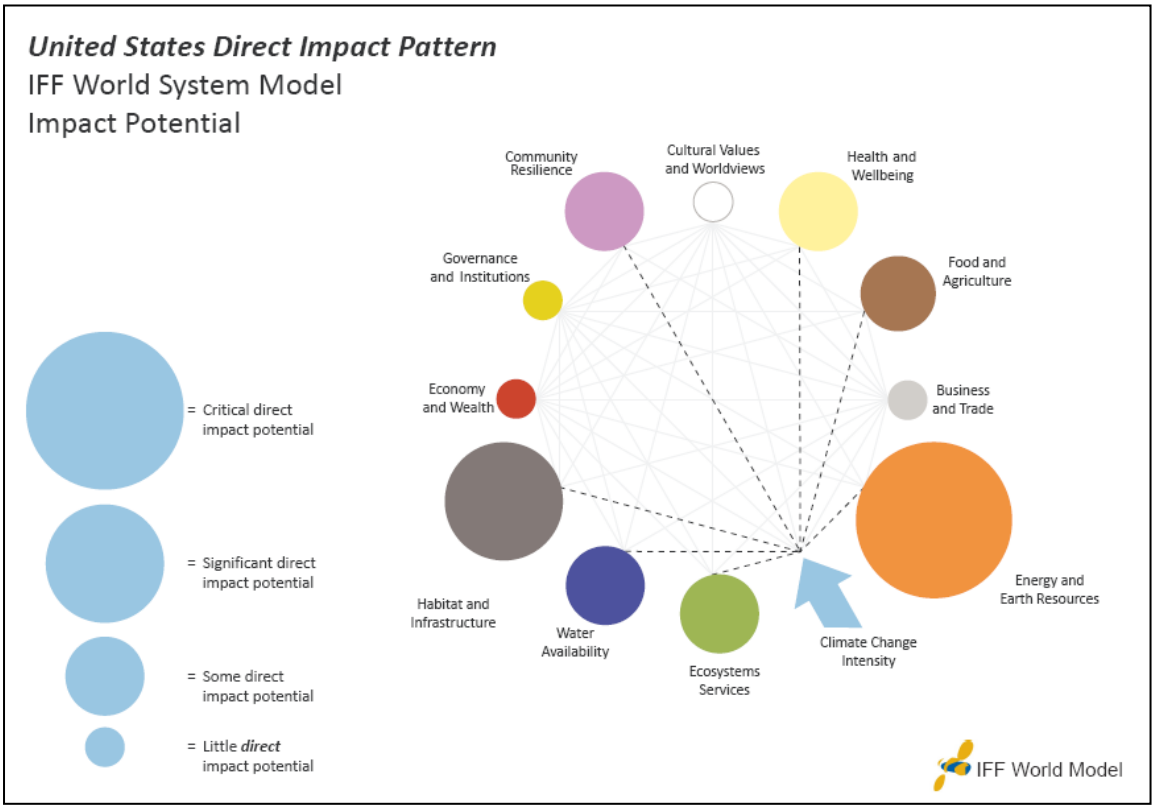


Figure 3.13.1 System Map showing the United States Direct Impact Pattern of climate change

Climate Sensitivity Position	*13 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*HIGH*	*Reference Book 1 Section 1 (p.187)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.13.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for United States

3.14 Australia Direct Impact Pattern

Australia is treated alone.

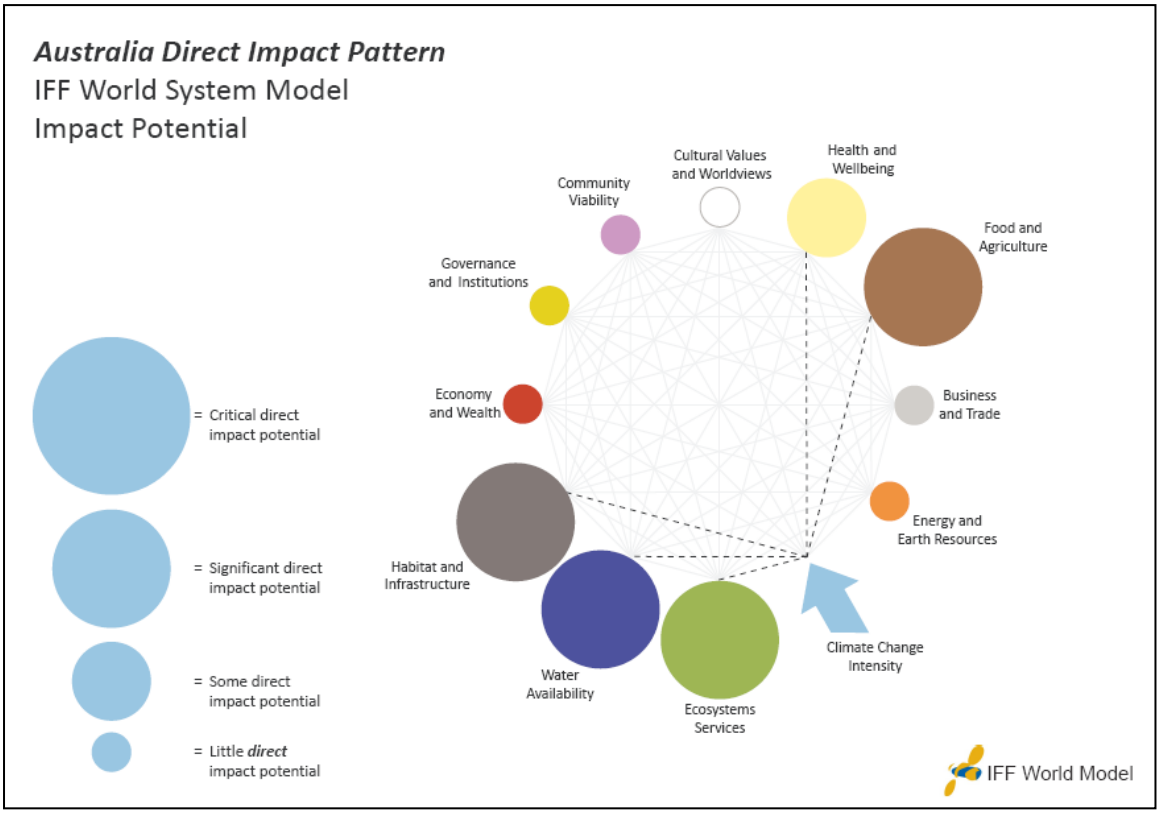


Figure 3.14.1 System Map showing the Australia Direct Impact Pattern of climate change

Climate Sensitivity Position	*14 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*HIGH*	*Reference Book 1 Section 1 (p.197)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.14.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Australia

3.15 Canada Direct Impact Pattern

Canada is treated alone.

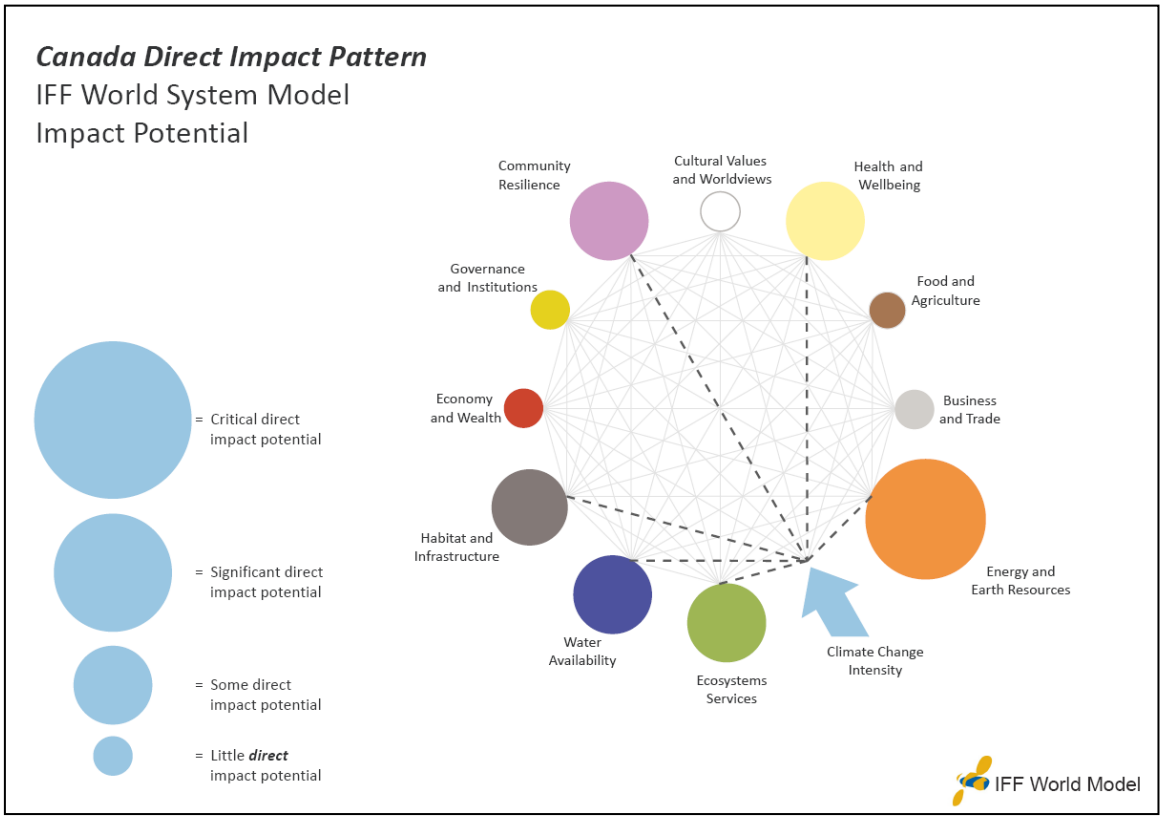


Figure 3.15.1 System Map showing the Canada Direct Impact Pattern of climate change

Climate Sensitivity Position	*15 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*HIGH*	*Reference Book 1 Section 1 (p.209)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.15.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Canada

3.16 New Zealand Direct Impact Pattern

New Zealand is treated alone.

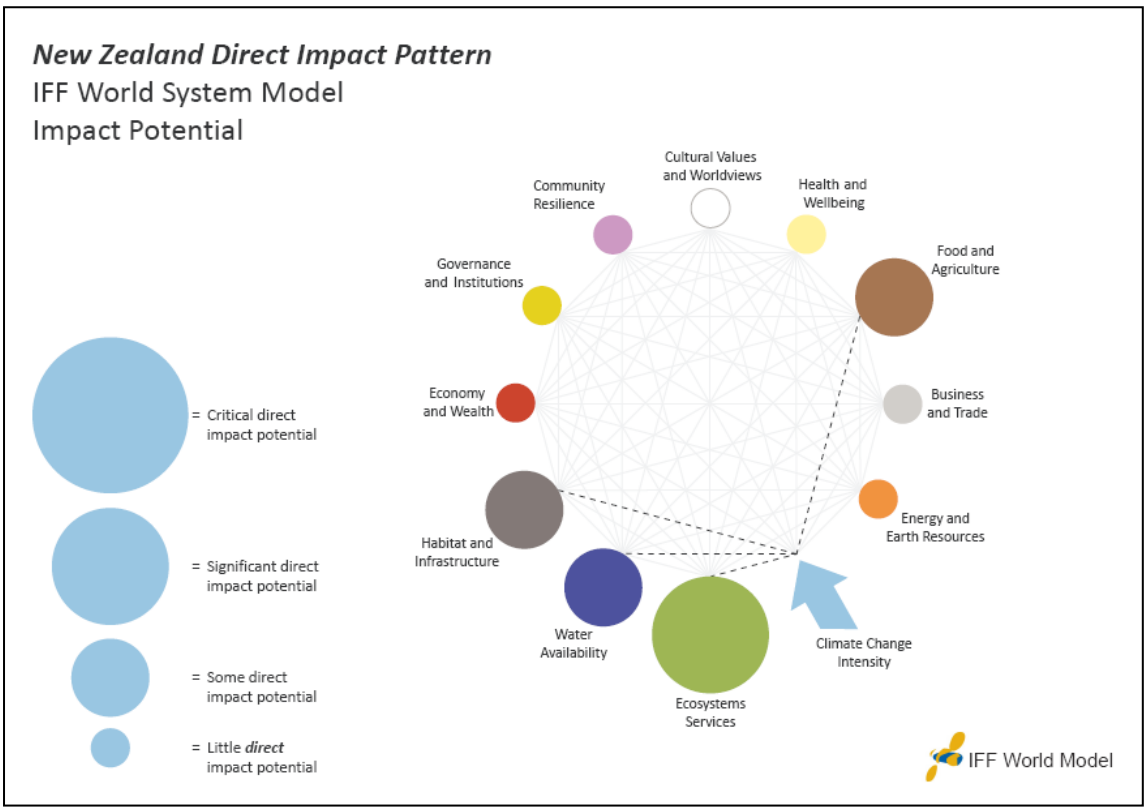


Figure 3.16.1 System Map showing the New Zealand Direct Impact Pattern of climate change

Climate Sensitivity Position	*16 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*HIGH*	*Reference Book 1 Section 1 (p.215)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.16.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for New Zealand

3.17 Russia Direct Climate Impact Pattern

Russia is treated alone.

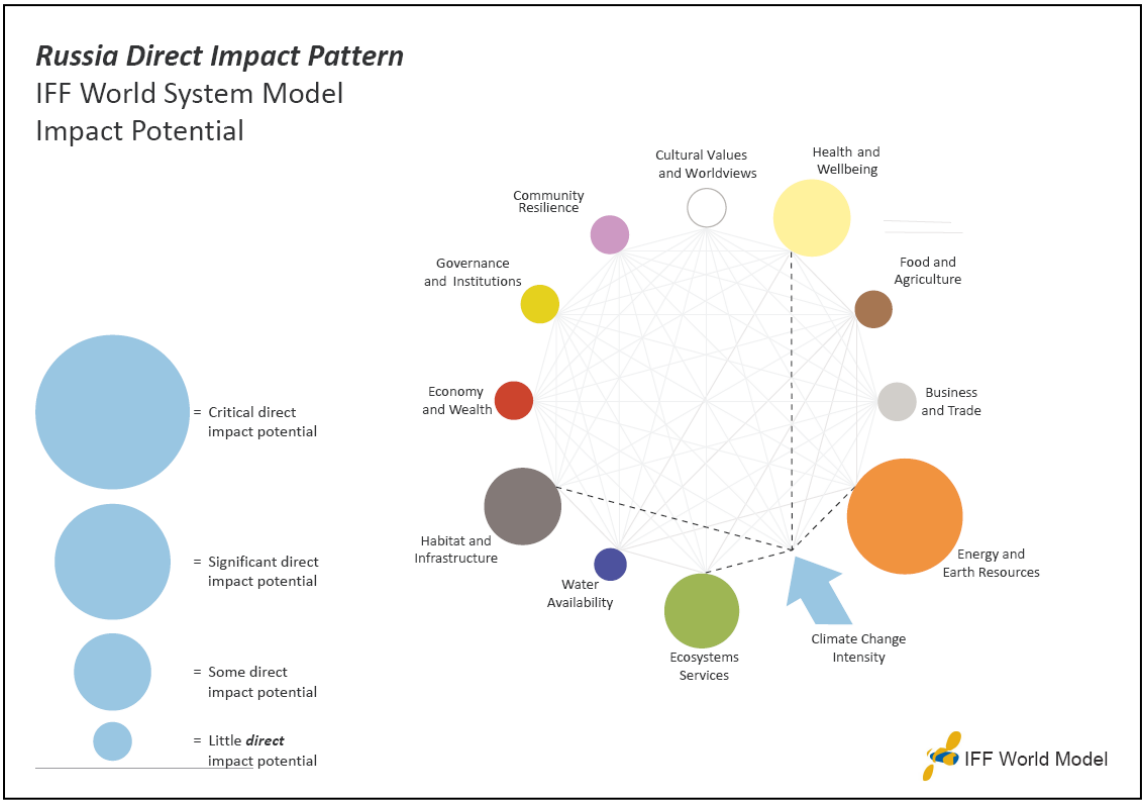


Figure 3.17.1 System Map showing the Russia Direct Impact Pattern of climate change

Climate Sensitivity Position	*17 out of 17*	*Reference Table 2.4 (p.34)*
Adaptive Capacity Rating	*MEDIUM*	*Reference Book 1 Section 1 (221)*
Overall Vulnerability	*LOW*	*Reference Table 2.6 (p35)*

Table 3.17.1 Climate Sensitivity Position, Adaptive Capacity Rating and Overall Vulnerability for Russia

3.18 UK Overseas Territories (UKOT) Direct Impact Pattern

The Territories reviewed are: Anguilla, Ascension, Bermuda, British Antarctic Territory, British Indian Territory, British Virgin Islands, Ocean Territory, Cayman Islands, Falkland Islands, Montserrat, Pitcairn Islands, St Helena, South Georgia & South Sandwich Islands, Tristan da Cunha, Turks and Caicos Islands.

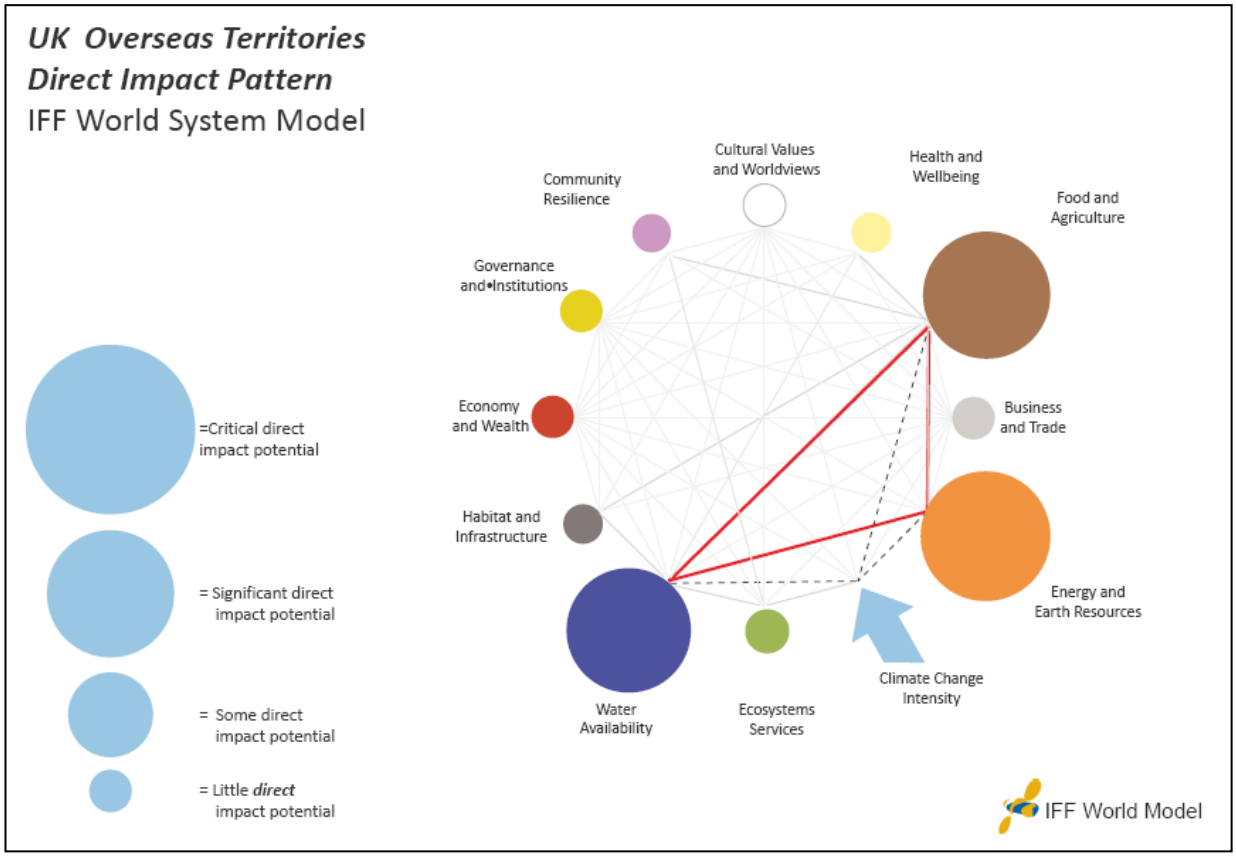


Figure 3.18. 1- Diagram showing the Direct Impact Pattern of climate change on UK Overseas Territories. Given the widely scattered positions of these islands the above picture may vary significantly from territory to territory.

3.18.1 Overview

The map in Figure 3.3.2 shows that the Territories are predominantly small islands quite widely scattered but with some grouping in relation to the main areas considered in this report. One problem, however, is that many are in wide reaches of ocean - which are not considered by the mainstream of global climate change and impact mapping. Potential impacts are more related to factors like sea level rise and storm patterns.

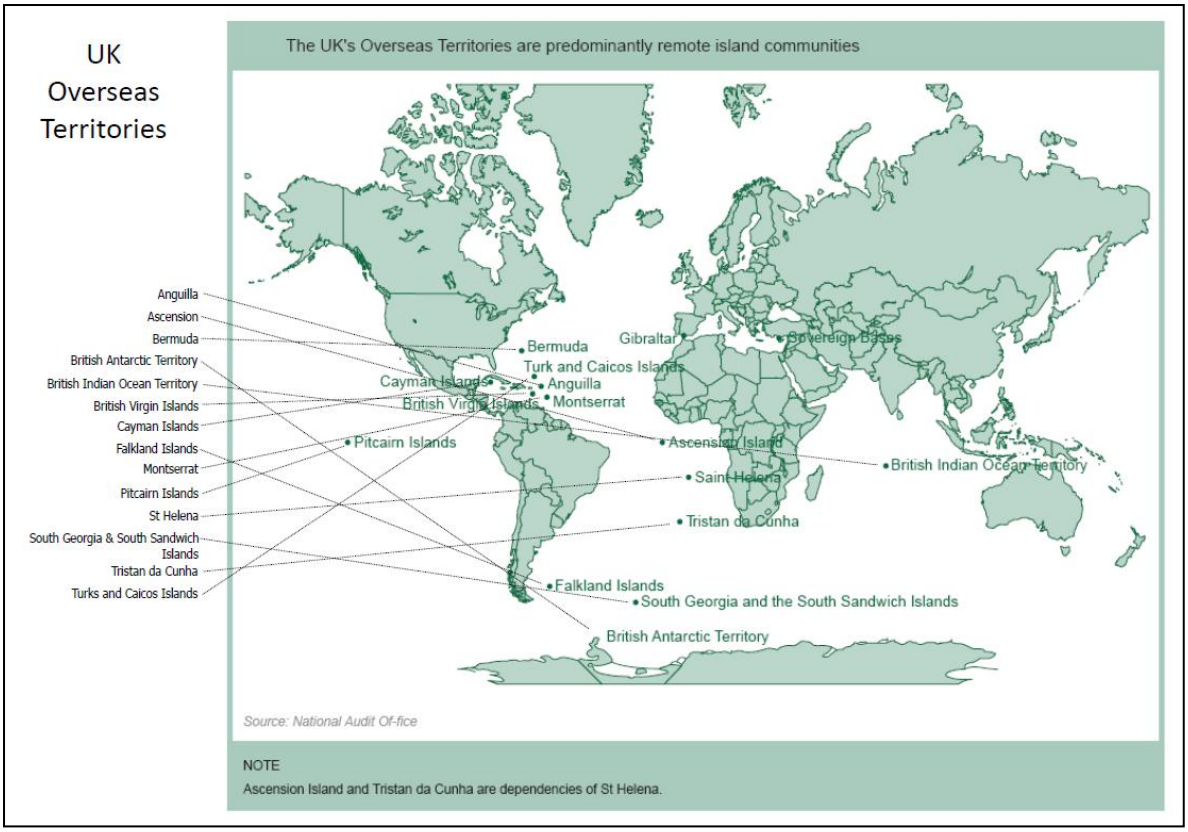


Figure 3.18.2 - Map showing the locations of the UK Overseas Territories

The general location of the bulk of the Territories in relation to global warming is shown in Figure 3.18.3 below as the shaded grey areas. Those islands clustered in the Caribbean region can in many ways be looked at from the perspective of the review of *Central America and the Caribbean* elsewhere in this report. (See Section 3.4 and Book 1 Section 1)

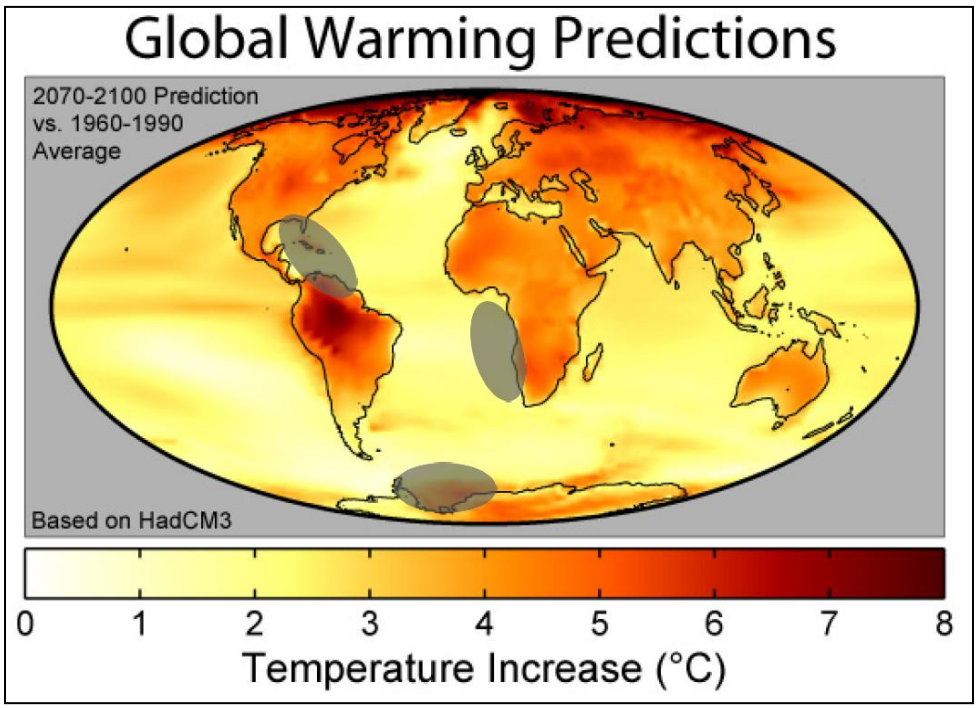


Figure 3.18.3 - Map showing *the general areas (shaded grey) in which UK Territories are concentrated relative to predicted global warming (Hadley Centre)*

In most of the Overseas Territories the interaction between food, energy and water is highlighted. For example, redressing shortage of water may place additional demands on energy which may become increasingly expensive. Also the increasing price of embedded water in food could become a stress factor in the future. The Direct Impact Pattern shown above represents a majority emphasis for the fifteen listed Territories taken as a whole. Given the wide geographical spread of these islands and their strong exposure to changes in the condition of the oceans and associated weather systems, for a proper analysis each island area would need to be studied independently.

A basis for such work has been compiled (Brown 2008) who emphasises the challenge of their diversity. "*Though disparate, as a group the UKOTs are very vulnerable to the effects of climate change. Several of the ecosystems*

found in the UKOTs, such as mangroves and coral reefs in the Caribbean and Pacific, sea ice biomes in the Antarctic, and Mediterranean-type ecosystems are among those that the IPCC has identified as "most vulnerable" and "virtually certain to experience the most severe ecological impacts" of climate change (Parry et al., 2007). In addition, the UKOTs (with the exception of the British Antarctic Territory and Gibraltar) are small islands, and small islands are expected to experience some of the most severe impacts of increasing temperatures (Mimura et al., 2007)."

3.18.2 Direct Impacts

There are some general considerations to note, some of which relate to the fact that most of the Overseas Territories are islands:

For a number of the Territories, changes in ocean temperature and acidification leading to changes to the marine food chain could put at risk their fisheries, which are for some a source of food but also in some cases their main or only source of income (by licensing and so on); In addition there are potential issues such as melting icecaps in Antarctica displacing land-based animals such as penguins from their normal feeding grounds, which could impact on species survival. This could be considered as part of ecosystem services, in terms of the integrity of the biosphere;

- There are the three territories with no permanent inhabitants and so no threat of impact on 'human habitat' – but where there is a risk of losing a massive amount of biodiversity;
- Few of the Territories produce their own energy and most are therefore highly dependent on imports. The energy issues confronting the Territories include: cost of importing energy from outside; high per capita emissions but still too small to have an impact on the environment locally or for the UK to trouble recording them; restrictions on the use of renewable energy in some Territories.

Note: A detailed review of each of the Overseas Territories is beyond the scope of this report so there is no detailed expansion in Book 2 Section 1.

SECTION 4 - Anticipating Possible Impacts on the UK of Climate Change Impacts Elsewhere in the World

Introduction

Direct climate impact on any region or country is absorbed in varying degrees depending on the adaptive capacity of that region or country. The UK itself is subject to the challenges of direct climate impact and has it's own specific capacities to adapt to it. However, the focus of this study is to look beyond this first order direct climate impact to a second order impact which arises when the vulnerability of a given world region could have repercussions for the UK due to some form of significant relationship with that region. This situation is represented in graphically Figure 4.1.

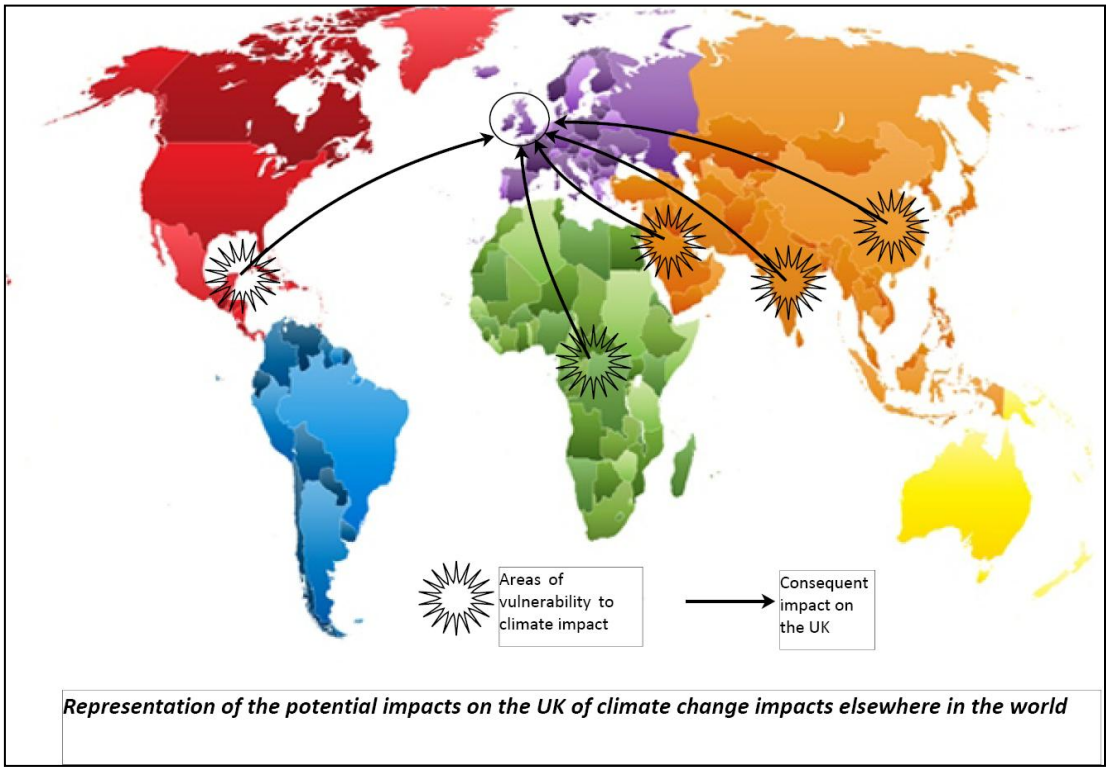


Figure 4.1- Map representing the *second order impacts of global climate change on the UK.*

The various regional and country vulnerabilities described in Section 3 are juxtaposed with a range of interdependencies that the UK has with different parts of the world. These interdependencies are analysed using a subset of the nodes of the World System Model, for reasons discussed in Section 1.6.

The selected nodes of the World System Model used to identify the second order relationships between the UK and other regions and countries are shown in Figure 4.2.

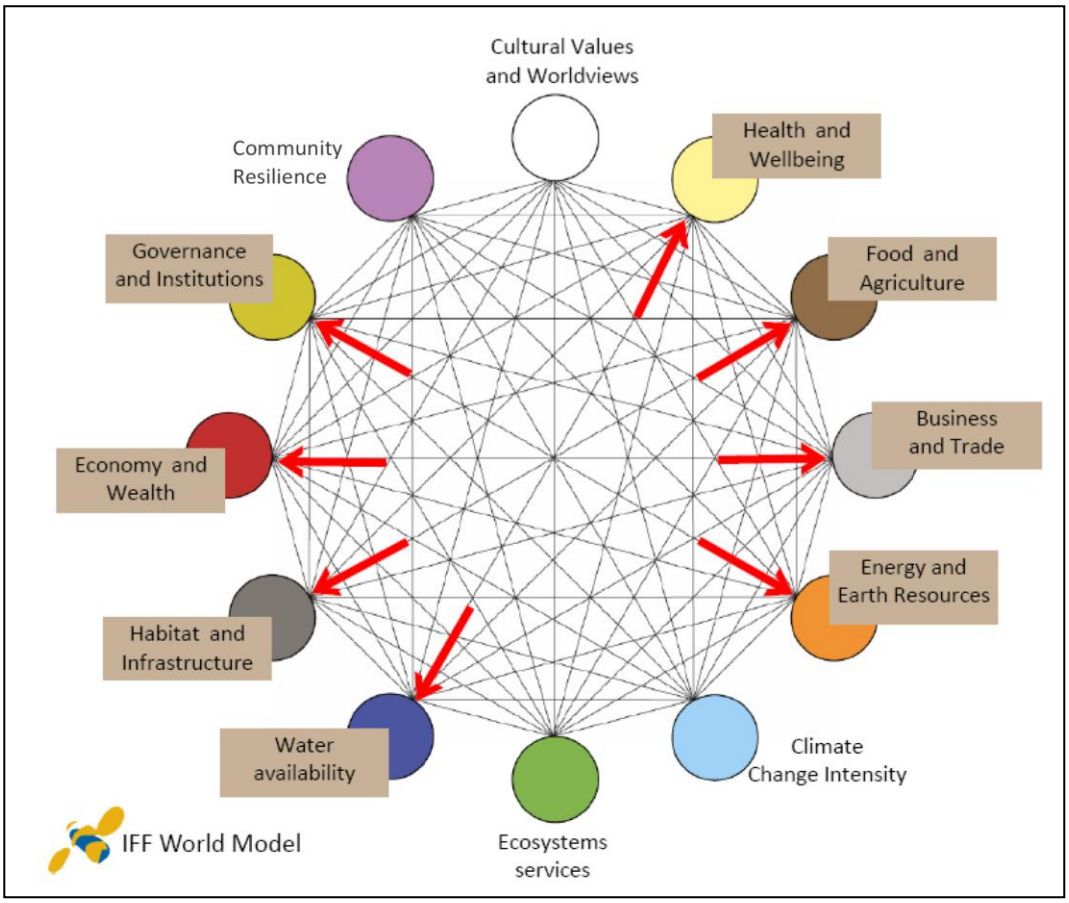


Figure 4.2 – The eight nodes of the IFF World System model selected to review impact on the UK of Climate Change Impact elsewhere in the world.

The eight nodes selected each have an associated question that helps focus a specific form of cross impact. They are:

1. *Food and Agriculture* – how might the UK's dependence on imported food be affected by climate change impacts elsewhere in the world?

2. *Business and Trade* – how might the UK's import and export dependencies be affected by climate change impacts elsewhere in the world?
3. *Energy and Earth Resources* – how might the UK's dependency on imported energy be affected by climate impact elsewhere?
4. *Water Availability* – how might the UK's dependence on embodied water in food imports be affected?
5. *Habitat and Infrastructure* – where is the UK's global trading infrastructure vulnerable to climate change impacts elsewhere?
6. *Economy and Wealth* – how is the UK's financial sector vulnerable to climate change impacts elsewhere?
7. *Governance and Institutions* – how far is the UK's response to climate change impacts elsewhere dependent on global governance institutions?
8. *Health and Wellbeing* – what might the implications be for UK public health?

The four unselected nodes are excluded since either they are predominantly subject to first order impacts or they relate to the UK's domestic adaptive capacity. *Climate change* is the node originating the first order impact; *ecosystems services* are directly impacted by climate change within the UK; *community resilience* is a major aspect of the UK's adaptive capacity which will determine its response to both first and second order impacts; *cultural values and worldview* is the general orientation of UK society to those impacts and views on their origin.

Using each of the eight selected nodes as categories, the literature was surveyed for specific UK dependencies and interdependencies with different regions of the world in relation to the appropriate key question. A comparative review was then made with the country and regional analysis in Section 3 and

the World Stories in Book 2 Section 1. This review was further supplemented by specific work packages on significant dependencies and inter-dependencies commissioned directly by the IDCC project. The whole of this information was then analysed with reference to the vulnerabilities of the relevant region or country as determined in Section 2 and summarised in Figure 4.3.

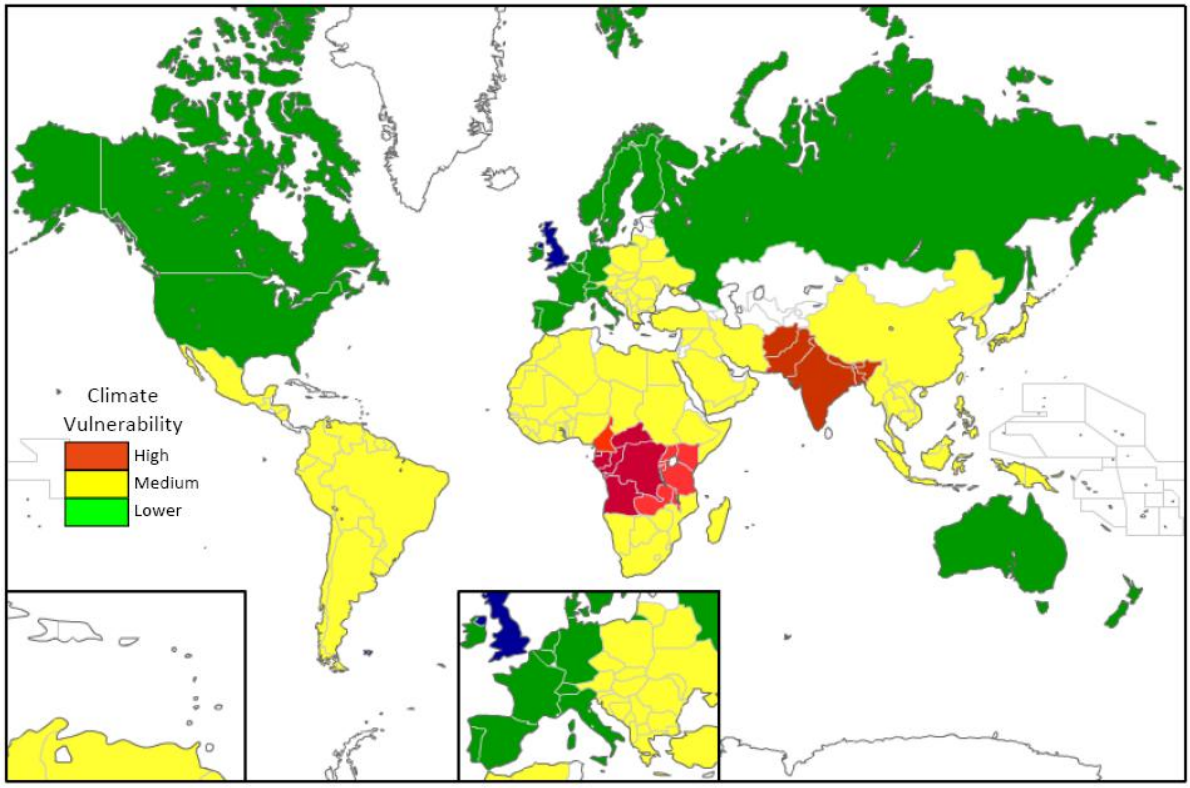


Figure 4.3 – Map showing the regional climate vulnerabilities as identified in Sections 2 and 3 and used in analysing the potential impacts on the UK

From the literature on UK interdependence, dependence and security related to a given node, the regions or countries that were the strongest sources of potential impact on the UK were identified. The next step in the process was to compare the UK dependencies with the world stories to characterise the specific potential impact on the UK. Where possible a rating of high, medium or low was applied to the geographically distinct sources of impact. This is a qualitative assessment by the authors based on factors such as scale (for example, volume of trade) and significance (for example, weight given by the reviewed authors to the impact issues). However, it became clear that in

many case the framing of impact as a simple causal arrow, as represented in Figure 4.1, was too simplistic. This issue was formulated as the *mediation of impact* question. The three categories of impact identified are described below.

Category 1 Impact – occurs where a dependence or relationship is disturbed by the impact of climate change on an interdependent region or country. For example, the collapse of a major crop growing region from which a significant amount of food is imported. This would be a direct supply impact in a bilateral relationship. However, if the dependency is also within a functioning global market, the impact will be felt as higher prices. A shortage of rice, for example, will drive up the global price. The commodity may still be available but at greater cost to the UK. This in turn may cause knock-on effects. In the food area, for example, it could lead to modifications of diet and substitution with different food types. In this category, the functioning of the market is likely to make adaptation relatively rapid.

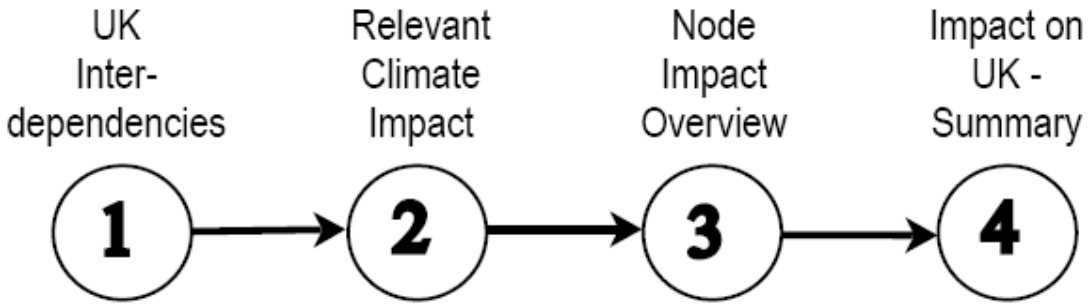
Category 2 Impact – occurs where the degree of impact is sufficient to provoke the need for substitution. As an illustration, in the field of energy security, the urgent need to reduce dependency on fossil fuel leads to a change of strategy towards the development of renewable energy. This category is, therefore, where the impact requires an increase in adaptive capacity relative to category 1 impacts requiring a serious commitment to a change of pattern. If left to market mechanisms alone, there will be a high risk of the market failing to ameliorate the impact. Market failure is often the indication of category 2 impacts.

Category 3 Impact – occurs where the impact of climate change elsewhere creates a major and probably irreversible dislocation. For example, severe climate change conditions could lead to a series of 'super-storms' that make both sourcing energy and sourcing livelihoods from

that region impossible. At this level there is local catastrophe and, if the region generates a globally essential commodity (such as fossil energy) then there are serious impacts which are global as well as critically significant for the UK. In category three the scale of events causing impact will be beyond the ameliorating effect of market mechanisms and beyond current adaptive capacity, and will require drastic measures such as rationing and other legislatory interventions or, in the extreme, large-scale civil contingency actions.

The summary conclusions from this second order analysis are collated on world maps indicating the likely geo-regional sources of certain potential impacts on the UK of climate change impact elsewhere. The maps are intended to provide a quick overview of the assessment which can then be elaborated through correlating the other data in that section. Goosen et al (2009) note that: "*Translating science and data to maps improves communication and use of science and data. By now there is a lot of information about climate change and impacts available, yet it is often difficult to express the information in a spatial way. Spatial presentation is important since spatial planners are used to working with information that is presented in maps. Leave the 'predict then act' principle. Be prepared to accept uncertainties. There is always the urge to produce more accurate data and better predictions. However, dealing with climate change and adaptation will always leave some level of uncertainty. Adaptation issues are not to be solved through more science and data alone. Incomplete data and uncertain maps can indeed be helpful in investigating robust adaptation strategies*."

In the review of the eight UK impact nodes, the analysis is structured in four sections, each building on the preceding section, as represented by the chart that follows.

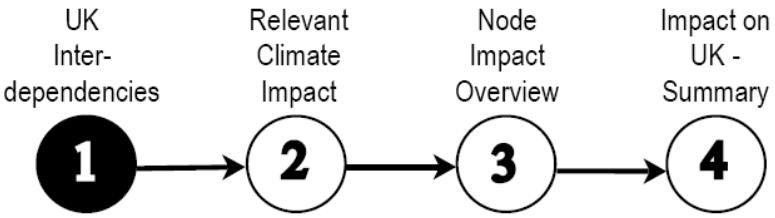


1. *UK Interdependencies* – For the given node (for example, water) a major interdependency is characterised together with the regions or countries that are the source of that interdependency.
2. *Relevant Climate Impact* – the direct climate impact in those countries is summarised based on profiles in Section 3 and the World Stories in Book 2 Section 1.
3. *Node Impact Overview* – the implications of the emerging picture are summarised on a geographic map, where possible giving some approximate grading of high, medium or low significance. This is based on the weight given to these factors in the literature.
4. *Impact on the UK Summary* – an overview of the areas of impact that the UK needs to take into account in its own adaptive planning.

4.1 Food and Agriculture

Focus Question: how might the UK's dependence on imported food be affected by climate change impacts elsewhere in the world?

4.1.1 UK Interdependencies



The self-sufficiency ratio of domestic production of food to consumption has been in decline over recent years indicating an increasing dependency of the UK on imported food (Defra, 2006). This clearly increases the potential for disruption to supply from various causes including the impacts of climate change. A recent Scenario Study by Chatham House (Ambler-Edwards et al, 2009) identifies climate change as one out of seven fundamentals that affect food security. "*Climate change is considered to be 'an important additional stress' on agricultural production systems already affected by high demand and degradation. It is identified as a factor in disruptive weather events that have caused widespread crop losses in recent years. The number of natural disasters is increasing over time, indicating that more extreme weather events are occurring. Climate change is also blamed for contributing to the more rapid spread of crop and animal disease and for changes in temperature and precipitation*."

The main geo-political regions upon which the UK depends for its imported food are shown in Figure 4.1.1.

Figure 4.1.1 Map of the main food dependencies of the UK, which are Western Europe, Mid and South Africa and the USA

The impact of climate change on food security is represented in Figure 4.1.2 below.

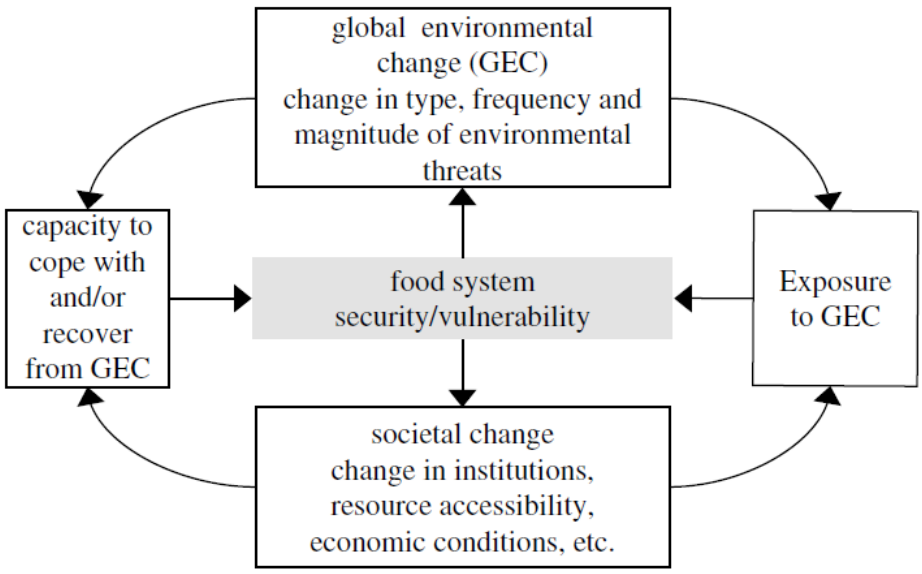


Figure 4.1.2 – Impact System of Global Environmental Change on the Food System (Gregory 2005)

The food system is impacted by exposure to global environmental change, the threats these changes pose, the capacity to cope with these changes, and the general resourcefulness of society to cope.

In the context of this global environmental exposure, the UK has food dependencies as shown in Figure 4.1.3.

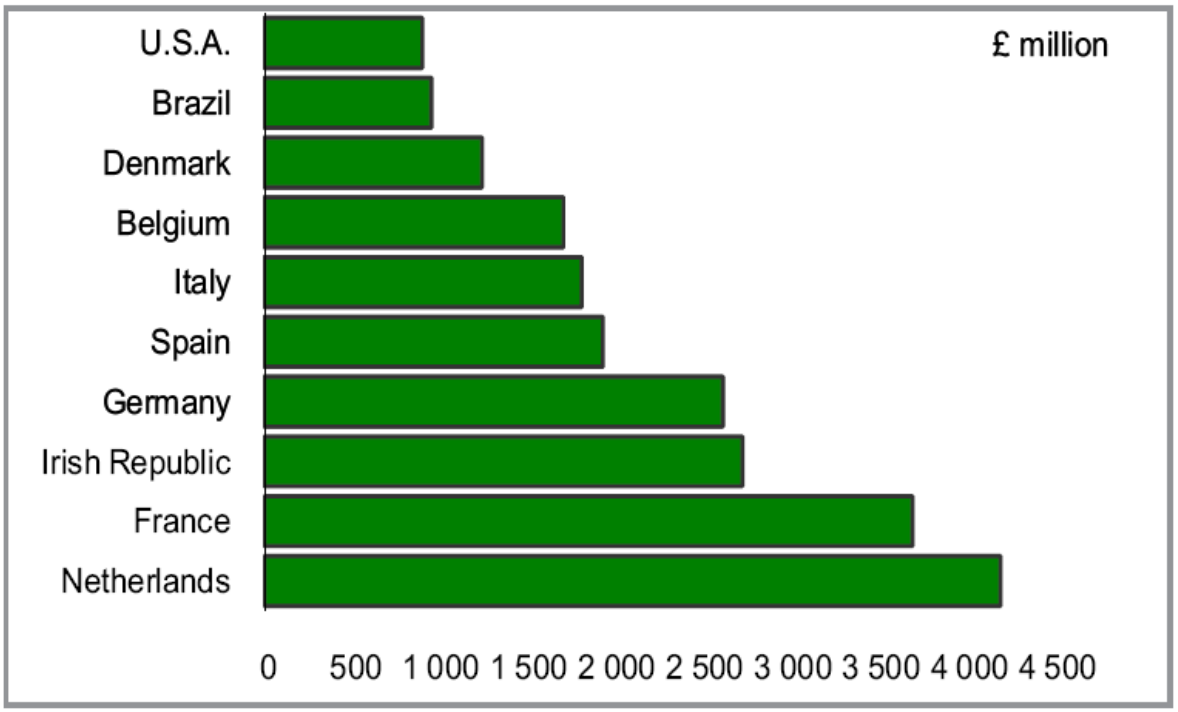


Figure 4.1.3 – UK *imports of food, feed and drink by source country 2008 (Defra 2009)*

This clearly shows Western Europe as a major food source of the UK's food, feed, and drink imports as contrasted with the small proportion of the USA and Brazil. Africa is also an important geographical source.

Although the UK sources over half of its food imports from the EU, the total masks a high level of reliance on non-EU sources for fruit, animal feed (soya), and fertilizers (some 32% of which are sourced from non-EU countries) (Ambler-Edwards, S. et al, 2009).

For example, the UK imported around 0.78 million tonnes (mt) of fresh fruit and vegetables from African nations in 2005 (See Figure 4.2.4). These goods had a declared value of £495m. South Africa was the largest supplier, accounting for around 0.37 mt in 2005. Six countries accounted for 95% of fruit and vegetable imports (Defra 2007).

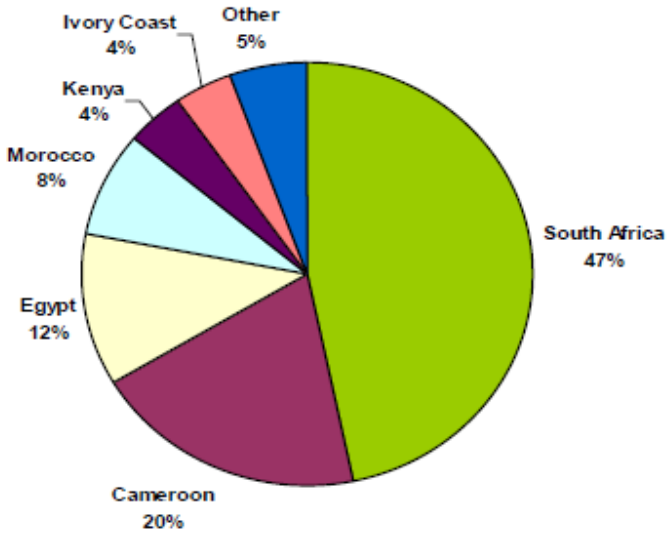


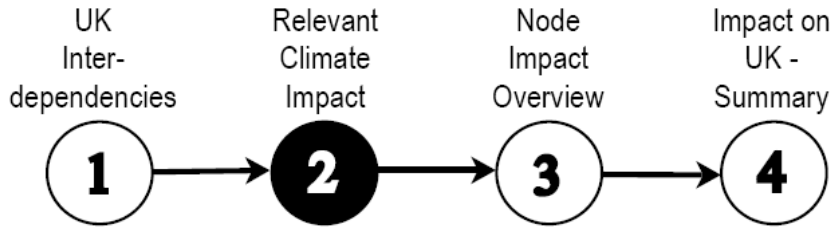
Figure 4.1.4 - UK import shares of African fresh fruit and vegetables by volume, 2005. (Defra 2007)

Regions and countries identified in this study with key UK interdependencies in food and agriculture based on the above data and as shown on the map Figure 2.1 are shown in Table 4.2.1.

Region	*Food dependency*	*Climate Vulnerability*
Western Europe	High – potential for serious disruption	Low
Mid Africa	Medium – potential for some disruption	High
South Africa	Medium – potential for some disruption	Medium
North Africa	Medium – potential for some disruption	Medium
USA	Lower – potential for minor disruption	Low

Table 4.2.1 - Food dependency and climate vulnerability

4.1.2 Relevant Climate Impact



There follows a note on each of the main countries and regions highlighted in the map Fig 4.2.1. The points made are extracted from the World Stories in Book 2 Section 1.

Western Europe

High food dependency; Lower vulnerability

The EU is likely to provide the bulk of UK food imports for the foreseeable future. Any reduction in UK capacity or difficulties in global supply (e.g. oil-price-led transport costs) will place even greater emphasis on regional (i.e. EU) sourcing (Chatham House 2009).
The review of climate impact in Western Europe (See Book 2 Section 1 7.1) highlighted the following areas of risk:

- The effects of climate change on agriculture and water will be quite different in the northern, southern and eastern regions of Europe, thus intensifying regional disparities
- Potential arable land area will decline
- North Atlantic fisheries are likely to increase in productivity
- Most European regions would experience yield improvements, particularly in Northern Europe
- Southern Europe would experience yield losses

This is a mixed picture which indicates gains as well as losses. Given the higher adaptive capacity of the region, a high risk to food security to the UK would seem unlikely.

Mid Africa

Medium food dependency; High vulnerability

Mid Africa is one of the most vulnerable areas to climate impact. In its food and agriculture sector it is particularly sensitive to climate, including periods of climate variability. In many parts of Africa, farmers and pastoralists also have to contend with other extreme natural resource challenges and constraints such as poor soil fertility, pests, crop diseases and a lack of access to essential inputs such as water and fertilizers. Overall the area suitable for agriculture, the length of growing seasons and yield potential are expected to decrease.

The review of climate impact in Mid Africa (See Book 2 Section 1 7.1) highlighted the following areas of risk:

- Climate change will act as a multiplier of existing threats to food security
- Increased heat and water stress will reduce agricultural productivity significantly
- Unabated climate change could, by 2080, mean an additional 30–170 million people suffering from malnutrition or under-nutrition, of whom a large proportion will be in Mid Africa
- The area suitable for agriculture, the length of growing seasons and yield potential are expected to decrease

This is largely a picture of increasing negative climate impact with little upside in a region of questionable adaptive capacity and hence higher vulnerability.

Southern Africa

Medium food dependency; Medium vulnerability

Many of Africa's economies are dependent on agriculture, fisheries, and forestry. Agriculture represents on average between 20 to 30 per cent of GDP in sub-Saharan Africa and makes up 55 per cent of the total value of African exports. Meanwhile, depending on the country, between 60 and 90 per cent of the total labour force in sub-Saharan Africa is employed in agriculture.

The review of climate impact in Southern Africa (See Book 2 Section 1) highlighted the following areas of risk:

- The implications of climate change for regional food security are serious. South Africa grows half of the subcontinent's white maize, a staple food for much of Africa, and was, until recently, self-sufficient in virtually all major agricultural products. But with the impacts of climate change, the national maize harvest is expected to fall over the next 50 years.

- Lower rainfall and higher air temperatures will affect fodder production and affect the marginal costs of ranching. Over the savanna regions in the northeast of the country, forage production may decrease by about one-fifth, seriously affecting the cattle ranching industry.

  The question of climate impact risk here is likely to depend on whether the impact shifts the balance of food demand in the population such that the margin for export is critically reduced.

  North Africa

  Medium food dependency - medium vulnerability

- Countries such as Morocco and Egypt have a large portion of their population employed in agriculture. The contribution of agriculture to GDP in North Africa is relatively high.
- Morocco and Tunisia's agricultural sectors have already been impacted by increasingly frequent droughts. Egypt, where agriculture is impossible without irrigation, is at risk of being impacted.

  United States

  Lower food dependency; low vulnerability

  Although the US represents only about 4% of UK imports, those imports tend to be staple foods like wheat, maize and rice. Any impact on their availability is also most likely to result in increased prices on the world market.

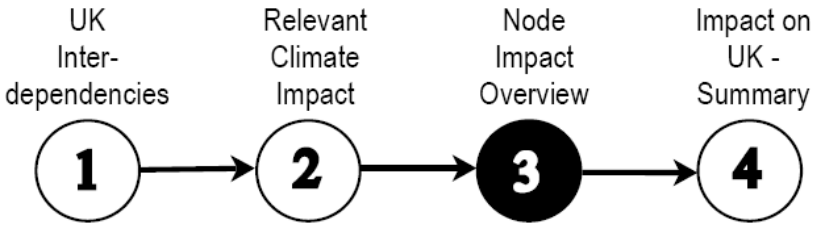
  The review of climate impact in the USA (See Book 2 Section 1) highlighted the following areas of risk:

- ♦ the United States will have an expanded share of the world's capacity to grow food
- ♦ yields of some annual crops such as cotton, maize, sunflower and wheat are expected to slightly decrease by mid-century

- the spread of population, industry and irrigated agriculture may consume the region's limited sources of water
- climate change induced transformations now underway in many semi-arid rangelands are reducing the quality of the forage
- extreme events may be among the greatest challenges, as they can lead to large loss of crops, impose stress on livestock, and be most difficult to manage

These impact predictions suggest that climate impact on the USA is likely to be uneven, with positive as well as negative impacts, thus with a lower risk to the UK.

4.2.3 Food and Agriculture Overview



The interdependencies are related to climate vulnerability in Figure 4.1.5 which links the food dependency relationship to the country or region and its climate vulnerability as determined in Sections 2 and 3.

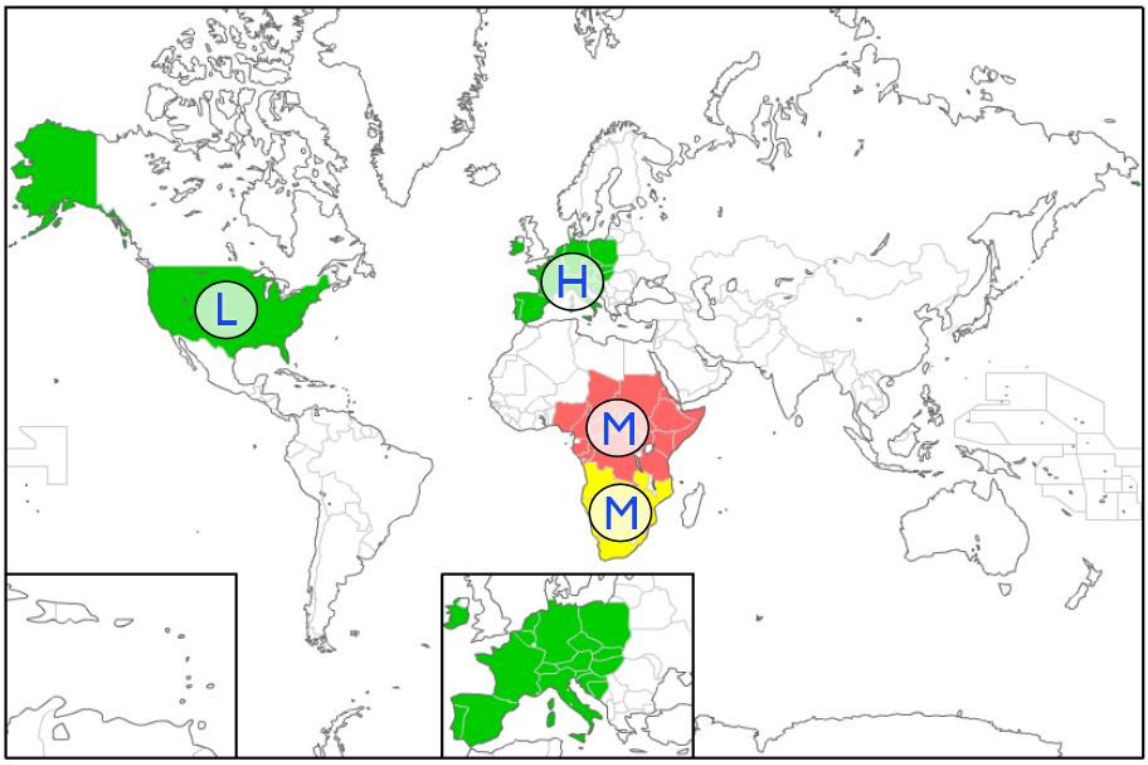
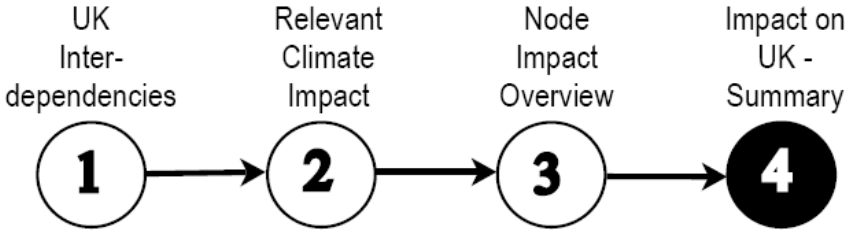


Figure 4.2.5 - Map detailing the regions and countries with a significant UK food security contribution and their level of potential vulnerability to climate change. Those regions marked H are relatively high dependence, those M are medium dependence and those marked L are lower dependence. The regions marked in red are highly vulnerable, those in yellow moderately vulnerable and those in green are considered reasonably resilient to any climate change impact.

4.2.4 Impact on UK Food and Agriculture - Summary



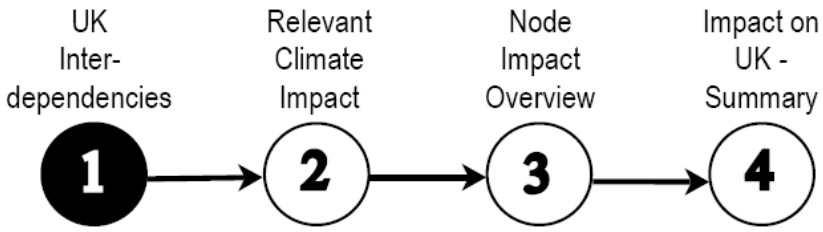
The food security of the UK is tightly coupled to Western Europe. African sources are probably not at a level to provoke a major crisis if reduced or cut off due to climate change impacts on those countries. The USA is a minor supplier and, although subject to climate change impact has high adaptive capacity and may be a source of increased supply.

It will be increasingly important to understand the dependencies inherent in the UK's food supply system, particularly those with a global dimension. The current underlying balance between domestic, EU and global sources may at first sight appear to score well in terms of resilience. The EU is by far the largest source of UK food imports. But there are key exceptions. The supply of fruit to the UK market is particularly reliant on global trade, the UK being only 10% self-sufficient in this sector. UK food production also continues to be critically dependent, particularly for key inputs such as animal feed (soya) and fertilizer on a small number of sources in the wider global market-place. In a world where trade of food and resources may become subject to more political control, these will need to be kept under critical review (Ambler-Edwards, S. et al, 2009).

4.2 Business and Trade

Focus Question: how might the UK's import and export dependencies be affected by climate change impacts elsewhere?

4.2.1 UK Interdependencies



According to Jones and Olken (2010), recent research has indicated that a warming of one degree Celsius in a given year lowers a country's total exports by as much as 5%. This effect appears to be only on poor countries. The geopolitical security and humanitarian ethical implications aside, rich countries can expect to suffer from reduced imports at higher prices.

"Historically, countries have warm and cold periods. They also have good and bad periods of economic growth. If weather fluctuations over time within a country are essentially random, then examining the historical association between idiosyncratic climatic shocks and growth episodes within countries can test whether climatic shocks have large or small economic effects. Together with Melissa Dell (Dell et al., 2008), we have taken this approach and find that warming has historically had negative impacts on economic growth – but only in poor countries. The effects in poor countries are remarkably large – with a 1 degree Celsius rise in temperature reducing economic growth by about 1.1 percentage points. Looking underneath national growth, the study also finds large effects on both agriculture and industrial value added, in addition to effects on aggregate investment, political stability, and innovation" (Jones and Olken 2010).

“When we examine the industrial breakdown of temperature’s impacts, we find substantial negative impacts not just on agricultural exports, but also on light manufacturing exports, such as electronic equipment, footwear, wood manufactures, and travel goods. We find little apparent effect on heavy industry or raw materials production. While the negative impact on agricultural exports is consistent with the primary thrust of the climate-economy literature, the negative impact on manufacturing provides further evidence that climate’s impact on economic activity may be much broader than conventionally implemented in climate-economy models that seek to guide policy” (Jones and Olken 2010).

Prompted by the above findings, the authors of this report analysed UK import and export values using latest data from the HM Revenue and Customs statistics would be a first step toward identifying potentially critical trade dependencies in the context of current climate change predictions. The data used were limited to the top 50 countries in relation to imports and exports (UK Tradeinfo, 2010). The analysis had the following stages.

The trade information figures were first consolidated to correspond to the country/regions grouping used in this report. This involved correlation of the import and export values (in millions of pounds Sterling).

Using the above data, the countries and regions were prioritised according to the value of imports (Table 4.2.1) and of exports (Table 4.2.2)

These two lists were consolidated to arrive at a ‘total value at stake’ for impact analysis (Table 4.2.3)

Regions on the list were partitioned into high, medium and lower as a basis for cross correlation with climate vulnerability.

Imports ordered by vulnerability

Ref No	Region	TOTAL
1	Mid Africa	873
2	Middle East	4066
3	Indian SC	6358
4	Central A+C	736
5	SE Asia	31714
6	China	21968
7	S Africa	4536
8	Brazil	2721
9	N Africa	961
10	C&E Europe	17325
11	And. S America	0
12	W Europe	189346
13	USA	28877
14	Australia	2295
15	Canada	6251
16	New Zealand	708
17	Russia	6694

Imports ordered by value (£millions)

Ref No	Region	TOTAL	L	M	H
12	W Europe	189346			
5	SE Asia	31714			
13	USA	28877			
6	China	21968			
10	C&E Europe	17325			
17	Russia	6694			
3	Indian SC	6358			
15	Canada	6251			
7	S Africa	4536			
2	Middle East	4066			
8	Brazil	2721			
14	Australia	2295			
9	N Africa	961			
1	Mid Africa	873			
4	Central A+C	736			
16	New Zealand	708			
11	And. S America	0			

Table 4.2.1 - Imports by climate vulnerability of country/region and by value of imports to the UK (rated on the right high (H), medium (M) and lower (L)). Numbers taken directly from UKTradeinfo, 2010.

Exports ordered by vulnerability

Ref No	Region	TOTAL
1	Mid Africa	1433
2	Middle East	8908
3	Indian SC	4119
4	Central A+C	850
5	SE Asia	14975
6	China	4870
7	S Africa	2541
8	Brazil	1618
9	N Africa	1664
10	C&E Europe	9146
11	And S America	272
12	W Europe	139071
13	USA	34964
14	Australia	2961
15	Canada	3596
16	New Zealand	0
17	Russia	4436

Exports ordered by value (£millions)

Ref No	Region	TOTAL	L	M	H
12	W Europe	139071			
13	USA	34964			
5	SE Asia	14975			
10	C&E Europe	9146			
2	Middle East	8908			
6	China	4870			
17	Russia	4436			
3	Indian SC	4119			
15	Canada	3596			
14	Australia	2961			
7	S Africa	2541			
9	N Africa	1664			
8	Brazil	1618			
1	Mid Africa	1433			
4	Central A+C	850			
11	And S America	272			
16	New Zealand	0			

Table 4.2.2 - *Exports by climate vulnerability of country/region and by value of exports from the UK (rated on the right high (H), medium (M) and lower (L). Numbers taken directly from UKTradeinfo, 2010.*

Total exchange ordered by vulnerability		
Ref No	Country/Region	TOTAL
1	Mid Africa	2306
2	Middle East	12974
3	Indian SC	10477
4	Central A+C	1586
5	SE Asia	46689
6	China	26838
7	S Africa	7077
8	Brazil	4399
9	N Africa	2625
10	C&E Europe	26471
11	And. S America	272
12	W Europe	328417
13	USA	63841
14	Australia	5256
15	Canada	9847
16	New Zealand	708
17	Russia	11130

Total exchange ordered by value (£mil)					
Ref No	Country/Region	TOTAL	L	M	H
12	W Europe	328417			
13	USA	63841			
5	SE Asia	46689			
6	China	26838			
10	C&E Europe	26471			
2	Middle East	12974			
17	Russia	11130			
3	Indian SC	10477			
15	Canada	9847			
7	S Africa	7077			
14	Australia	5256			
8	Brazil	4339			
9	N Africa	2625			
1	Mid Africa	2306			
4	Central A+C	1586			
16	New Zealand	708			
11	And. S America	272			

Table 4.2.3 - *UK Trade Figures ranked by climate vulnerability and by financial value of total imports and exports (rated on the right high (H), medium (M) and lower (L))*

In table 4.2.1 on the left, imports are grouped according to the scale of climate vulnerability shown in Table 2.5 and then in quantitative value in descending order. On the right, the countries are re-ordered according to value of imports. In table 4.2.2 on the left, exports are grouped according to the scale of climate vulnerability shown in Table 2.5 and then in quantitative value in descending order. On the right, the countries are re-ordered according to value of exports.

On the assumption that impact on the UK is likely to be a function of total imports and exports, Table 4.2.3 shows a consolidated view.

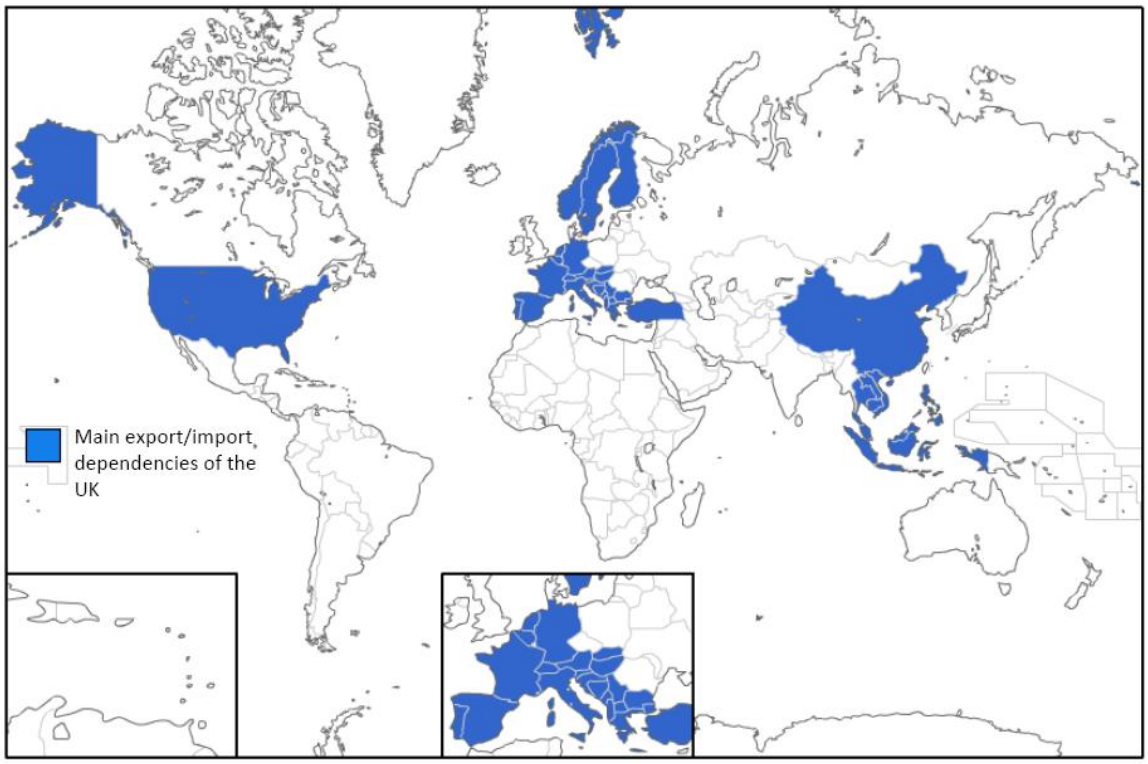
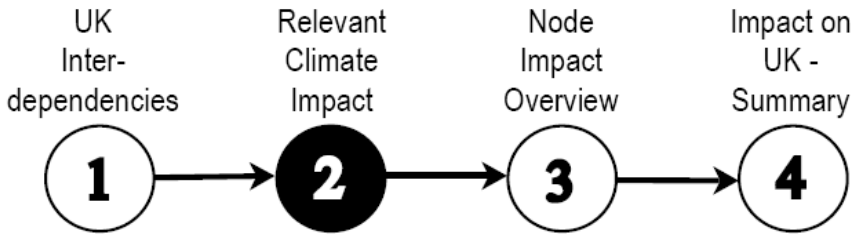


Figure 4.2.1 Map *showing the main import/export regional dependencies of the UK.*

The exposure levels indicated in Table 4.2.3 are used to show dependencies on the map in Fig 4.2.1

Other trade dependencies not highlighted could also have an impact on the UK if they were all affected by climate change simultaneously. The cumulative effect on UK trade would initially affect market prices of certain goods in Category 1 impact.

3.2 Relevant Climate Impact



There follows a note on each of the main countries and regions highlighted in the map Fig 4.2.1. The points made are extracted from the World Stories in Book 2 Section 1.

Western Europe

High Trade Dependency; Low Vulnerability

- The effects of climate change on agriculture and water will be quite different in the northern, southern and eastern regions of Europe, thus intensifying regional disparities
- ♦ Potential arable land area will decline
- Most European regions would experience yield improvements, particularly in Northern Europe
- Southern Europe would experience yield losses
- There is a danger that the melting of the permafrost may lead to problems with the pipelines supplying Russian natural gas to Western Europe
- Water scarcity around the Mediterranean will effect agricultural productivity

United States

Medium Trade Dependency; Low Vulnerability

- ♦ Extreme events may be among the greatest challenges, as they can lead to large loss of crops, impose stress on livestock, and be most difficult to manage

- The United States of America is the world's largest energy producer, consumer, and net importer. Any disruption to supply can cost industry dearly
- Several thousand offshore drilling platforms, dozens of refineries, and thousands of miles of pipelines are vulnerable to damage and disruption due to sea-level rise and the high winds and storm surge associated with hurricanes and other tropical storms
- The recent natural disasters of Hurricanes Katrina, Rita and Wilma (all in 2005), highlighted just how susceptible the US's infrastructure can be. Increasing populations and further development on coastal areas will continue to put pressure on vulnerable infrastructure
- Climate change (along with peak oil) is likely to bring demands on energy resources (including the development of low emission infrastructure) that will severely challenge the viability of the suburban way of life, which is highly dependent on fossil fuels for private and public transport.

SE Asia

Medium Trade Dependency; Medium Vulnerability

- The increasing number of urban poor around the fast growing mega-cities of South East Asia will be particularly at risk as climate change will increase the frequency and severity of periodic droughts and floods.
- Rice production determines food security for many countries, as it is the only major grain grown exclusively for food and provides over one fifth of the calories consumed worldwide. With continued population growth in South East Asia, climate impacts on rice yields could have very serious consequences.
- Increases in sea level associated with climate change are particularly problematic for South East Asia, which is comprised of low-lying coastal and island nations. In fact, 20% of all the people worldwide living in low lying coastal regions, live in SE Asia.

- International studies have projected the displacement of several million people from the region's coastal zone in the event of a 1-m rise in sea level.

China

Medium Trade Dependency; Medium Vulnerability

- The North China Plain is the largest agricultural production area in China. In the next 20-50 years, agricultural production may be seriously affected, compromising long-term food security for all of China.
- Global warming could lead to a drop of between 20 and 37 percent in China's yield of rice, wheat and maize over the next 20 to 80 years.
- The extensive use of groundwater for irrigation agriculture under variable climatic conditions has resulted in the rapid decline of the groundwater table, especially in areas north of the Yellow River, leading to hydrological imbalance and unsustainable agricultural production.
- The increasing frequency and intensity of extreme weather events such as typhoons has the potential to threaten China’s economic development at local, regional, and national levels.

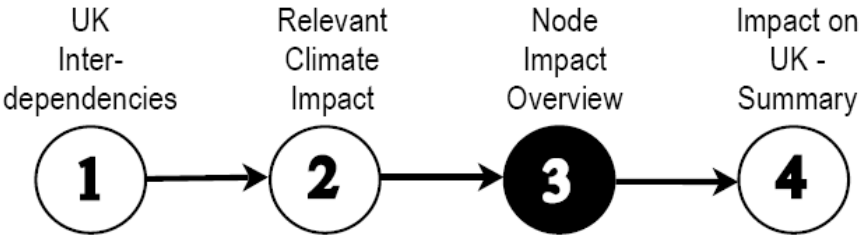
Central and Eastern Europe

Medium Trade Dependency; Medium Vulnerability

- The built environment of the former Eastern Bloc is acutely vulnerable to physical changes from climate variability and extremes. Floods are an obvious threat in many cities.
- Extreme heat waves can pose a serious threat to uninterrupted electricity supplies, mainly because cooling air may be too warm and cooling water may be both scarce and too warm. This can result in reduced capacities and reduced efficiency rates.

- The increasing incidences of extreme weather events and other environmental stresses could lead to more rapid declines in the condition of infrastructure

3.3 Business and Trade Overview



Taking the map of trade interdependence Fig 4.2.1 and relating it to the vulnerability of the countries and regions involved, the following map Fig 4.2.2 shows the relationship between those interdependencies and climate vulnerability.

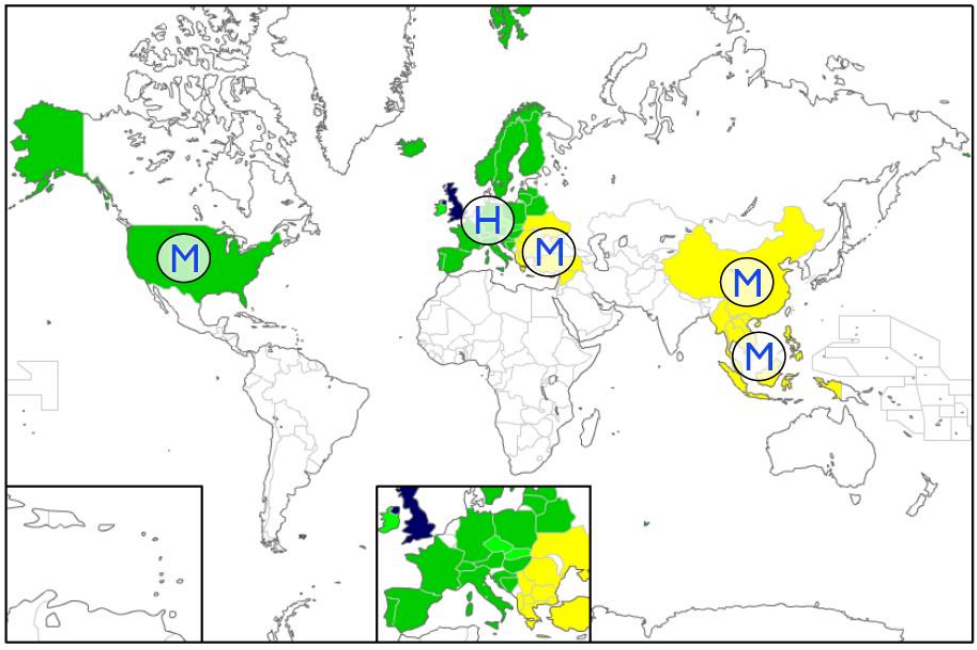
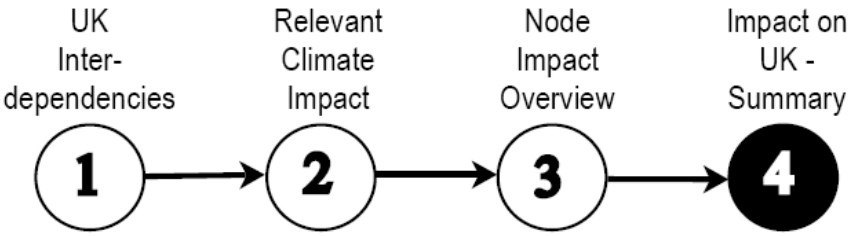


Fig 4.2.2 - Map showing the climate vulnerability of the countries/regions upon which the UK has most trade dependency in terms of imports and exports.. Those marked H have a high trade dependency level and those marked M a medium dependency. If any of these countries suffer disruption from climate change impacts then there would be repercussions on the UK.

4.2 Impact on UK Business and Trade - Summary



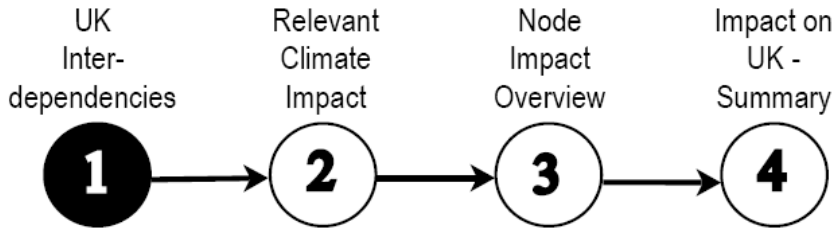
The impact of climate change elsewhere in the world on business and trade for the UK will be mediated by the market as a Category 1 impact (see Introduction to Section 4) with obvious price implications and a high likelihood of increased competition. Severe curtailment of availability will risk a jump to the next level of a Category 2 impact and provoke a serious search for alternative sources of supply or substitutes. Breakdown of critical supplies that are currently under the free market may become the focus of bilateral negotiations and even conflict.

The above analysis carries the reservation that the cumulative effect of synchronous failures due to climate change in various countries, not identified as key trade dependencies here, could also have severe trade and economic implications for the UK. This would be a global amplifying effect. Climate change is a global phenomenon and will act on all countries to a varying degree. The cumulative effect of climate impacts on global trade and the UK is impossible to predict with any certainty.

4.3 Energy

Focus Question: how might the UK's dependency on imported energy be affected by climate impact elsewhere?

4.3.1 UK Interdependencies



This section explores whether the UK is at risk from climate change impacts elsewhere in the world with regard to the supply of energy to meet demand. The primary emphasis will be on energy. Impact in the field of energy and commodities, except in exceptional circumstances, is largely mediated by a global market. This kind of impact falls into Category 1 effect as outlined in the introduction to this section 4.1. Thus the effect of impact will largely be one of availability affecting price. However, it is possible that climate impact superimposed on other factors (especially factors like geopolitical conflict or supply disasters) could multiply risks to create Category 2 effects. Such scenarios would provoke increasing bilateral arrangements as to how nations procured their energy supply. This is to some extent an already existing trend though so far not driven by climate change.

According to a recent parliamentary review of UK energy security "*We are entering a period where the UK will become increasingly reliant on imports to meet its energy needs, during the transition to a low-carbon economy. In the longer term, depending on the technologies which provide our future energy, this import reliance may fall again. Relying on imports is not new for the UK - we were for example heavily reliant on imports in the years before the exploitation of North Sea oil and gas - but the energy security challenges presented by a dramatically changing global economic, geopolitical and*

energy landscape, combined with the urgent need to tackle climate change, are new and require us to re-assess our approach" (Wicks 2009).

Climate change poses a growing threat to energy infrastructure. A recent report from the insurance industry states: "*Climate change creates many risks and uncertainties for society and industry. Anticipated disruption around energy, water and other critical natural resources pose new political, economic and human security challenges*" (Froggatt and Lahn 2010).

The supply side of energy relates to the region from where the oil and gas is procured and also to the transportation infrastructure. Saudi Arabia, Russia, Iran and the UAE make considerable amounts available for export. While the North American countries are high producers, most of this goes to satisfy domestic demand. The USA is a net energy importer. Key emerging players are Kazakhstan and Nigeria which have the potential to expand oil production considerably with most additional production available for export, although security and other concerns remain limiting factors at present. Iraq is expected once again to become one of the most important oil suppliers to the global market by 2030.

The UK is increasingly a net importer of energy, having enjoyed a period of energy self-sufficiency and energy export. Figure 4.3.1 shows the history of UK oil imports and exports. (Wicks 2009)

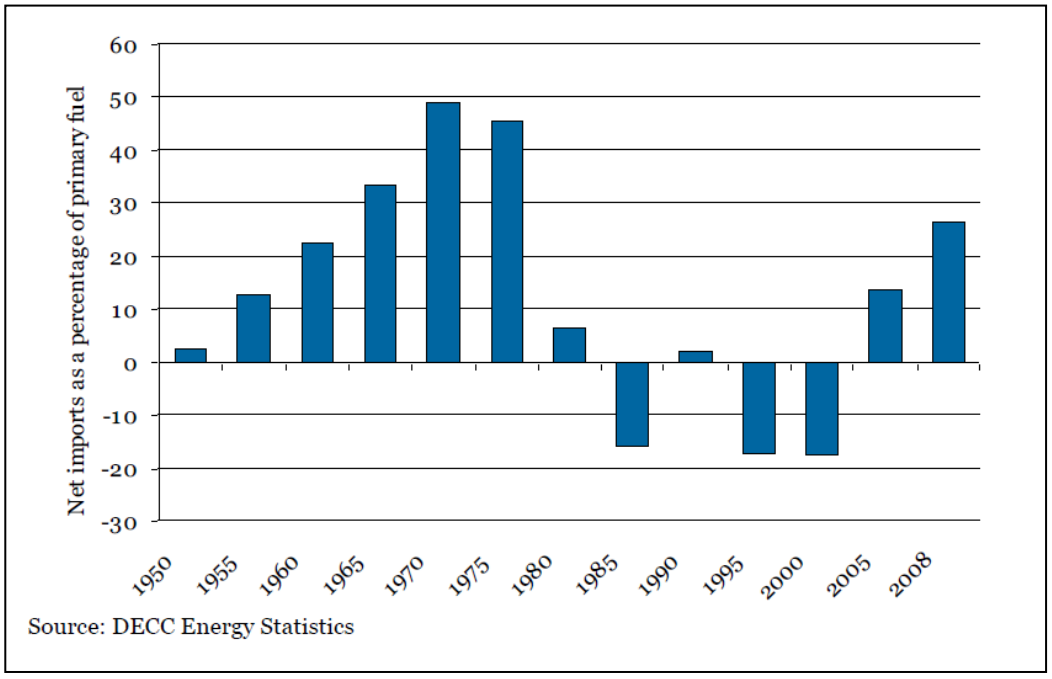


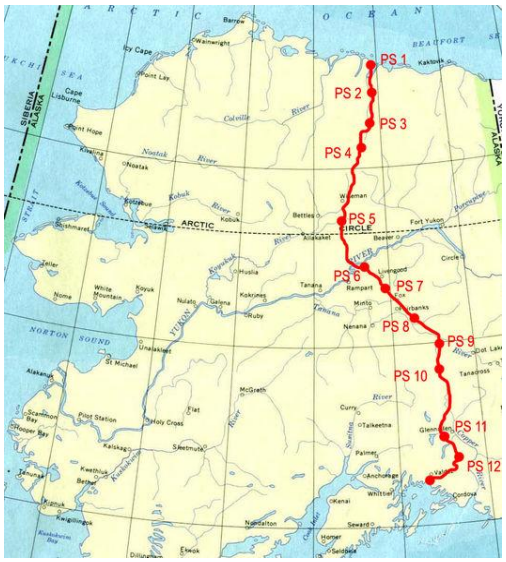
Figure 4.3.1- Net energy imports as a percentage of primary fuel 1950 to 2008. (Wicks 2009)

Oil is essentially mediated by the spot market which is supplied mainly by the countries shown on the map in Figure 4.3.2. Both oil and gas extraction and supply, however, are subject to potential climate and weather disruption of infrastructure. Platforms, pipelines and terminals can also be affected by a variety of environmental and political changes.

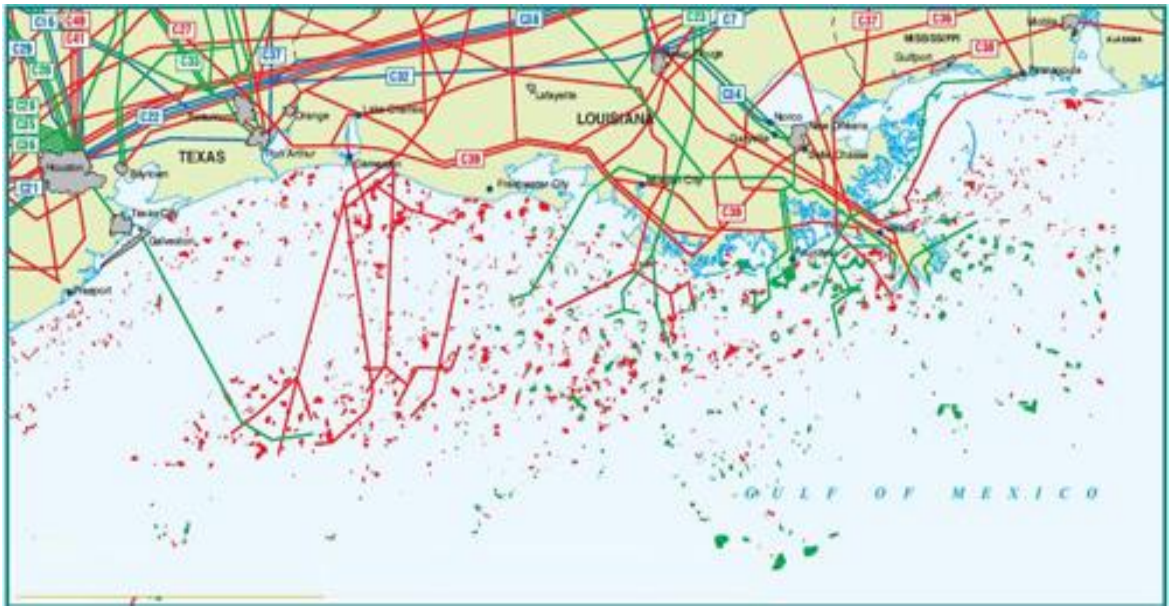
Figure 4.3.2 – Map of the main energy market dependencies of the UK. These are mainly the OPEC countries and Russia.

The transportation of energy is at high risk from severe climate change. The maps (see Fig.4.3.3 and 4.3.4) below give an overview of the main pipeline patterns which could be at risk to a variety of potential climate impacts from tundra melting to severe hurricanes or typhoons.

Figure 4.3.3 – The US oil and gas supplies most vulnerable to climate change impacts (below)



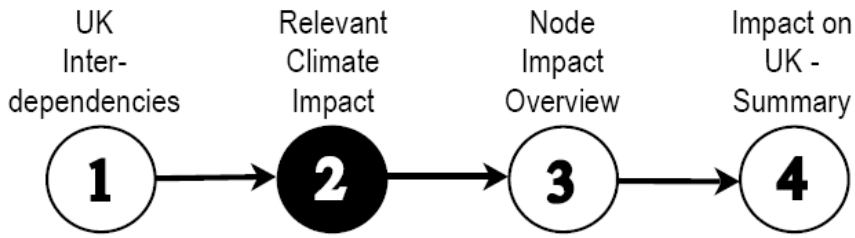
(a) Alaska (Flomunator en.wikipedia.org)



(b) the Gulf of Mexico (http://www.theodora.com/pipelines/united_states_gulf_of_mexico_pipelines.html)

(c) Russia Crude Oil, natural gas and product pipelines showing exposure to potential tundra instability (World Factbook www.theodora.com)

4.3.2 Relevant Climate Impact



There follows a note on each of the main countries and regions highlighted in the map Fig 4.3.2. The points made are extracts from the World Stories in Book 2 Section 11.

Middle East

High producer; High vulnerability

- The region is almost entirely dependent on oil and natural gas for its energy needs, and some countries derive substantial economic benefits from these industries. Sea level rises and possible shifts in the reach of tropical cyclones could potentially put key export and refinery infrastructures at risk.
- Little of the fossil fuel resource wealth lies in Israel, Palestine, Jordan, and Syria. Just like with water, access to Earth resources is unevenly distributed across the Middle East, creating a resources based potential for conflict exacerbated by climate change.

Africa

North Africa: Lower producer; Medium Vulnerability

Mid Africa: Medium producer; High vulnerability

- West Africa is expected to be one of the faster-growing sources of oil and gas for the American market.
- Deforestation is responsible for 20% of annual global CO_2 emissions and constitutes the main source of greenhouse gases from many developing countries.
- The biodiversity of tropical forests in Africa is being threatened by a range of human activities such as oil exploration and production, mining, habitat loss due to conversion to agricultural land and logging, over-exploitation for fuel wood, food, medicinal plants, overgrazing, water catchment and river channel destructions some of which are in response to climate change pressures.

Brazil

Lower producer; Medium vulnerability

- Increased fluctuation in water availability due to climate change could affect Brazil's hydro-electric generating capacity which provides more than 43% of the country's current electricity supply. In addition the mining industry, oil industry and the agriculture & biofuel sector could also be affected by these fluctuations in water availability thereby reducing the margin of fossil fuel for export.
- The increasing incidence of extreme weather events and other environmental stresses could lead to a more rapid decline in the condition of infrastructure across the country. It is likely that the weather events that different types of infrastructure are built to withstand will occur more regularly, and that more intense events will also increase in frequency, putting many types of infrastructure at significant risk by the middle of the 21st century.

Russia

A Special Case (see below)

High producer; low vulnerability

Russia is a vital energy supplier, not only to Europe, but also to East Asia. Currently, the EU depends on Russia for 33% of its oil and 42% of its gas imports, with growing dependency in both sectors. Sales of gas and oil to Asia are increasing with the construction of new pipelines, including the 4,700km East Siberia-Pacific Ocean oil pipeline, which reached China in 2009.

Russia's most important industry ("*in 2009 Russia was the world's largest exporter of natural gas, the second largest exporter of oil*" CIA

Fact Book 2011) petroleum, relies on pipelines built on permafrost that is rapidly melting due to climate change

- The Arctic Ocean holds an estimated one quarter of the world's oil and natural gas. The resource is becoming increasingly available as the Arctic warms up
- Existing and future energy infrastructure for the all-important petroleum industry will experience more pronounced challenges — structural subsidence, risks associated with river crossings, and construction difficulties as permafrost thaws earlier and deeper impeding the construction of vital new production areas.

South East Asia

Lower producer; Medium vulnerability

- Increases in the frequency of severe weather events could disrupt oil and gas productions.
- Note the importance of the shipping routes (e.g. the Straits of Malacca) that could be affected by increased high category storms.

United States

A special case (see below).

High consumer; Lower vulnerability

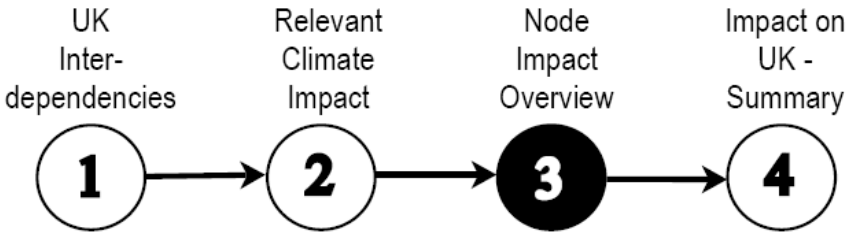
Note: The USA is also a high producer.

Although the United States is a net importer on a large scale of over half its fossil fuel consumption, it is also a large producer for domestic consumption. One of the key US producing areas is the Gulf of Mexico. The overall climate vulnerability (given its high adaptive capacity) is graded as lower. However, climate impact is subject to large local variation and the Gulf is well known for its massive hurricanes. “Events

such as Hurricane Katrina cannot be attributed to climate change directly, but do demonstrate the potential for weather and climate extremes to cause significant damage and raise prices, at least in the short term" (Met Office 2010). This indicates that a shock disruption of production and refining in the Gulf of Mexico would have very strong repercussions to the spot market and could trigger a breakdown into dominant bilateral energy grab or even further 'oil wars'.

The EIA (2009) reported that the United States total net oil imports (crude and products) of 12.2 million bbl/d in 2005 represented around 58 percent of total U.S. oil demand. Overall, the top six suppliers of crude oil to the United States during January-August 2005 were Canada (1.6 million bbl/d), Mexico (1.6 million bbl/d), Saudi Arabia (1.5 million bbl/d), Venezuela (1.3 million bbl/d), and Nigeria (1.0 million bbl/d).

4.3.3 Energy Overview



The risks that climate change elsewhere will affect the availability of energy in the UK are minor compared to the wider geopolitical and economic considerations. However, extreme changes could undermine infrastructure in Russia as a main supplier and cause knock-on shock effects exacerbated by massive reduction in United States domestic production. These effects may be greater than the market can absorb and drive prices to levels that will impact on the UK domestic economy.

The map in Figure 4.3.4 details the regions and countries with a significant UK energy security contribution and their level of potential vulnerability to climate change. That dependence is largely moderated through the global markets as a Category 1 impact.

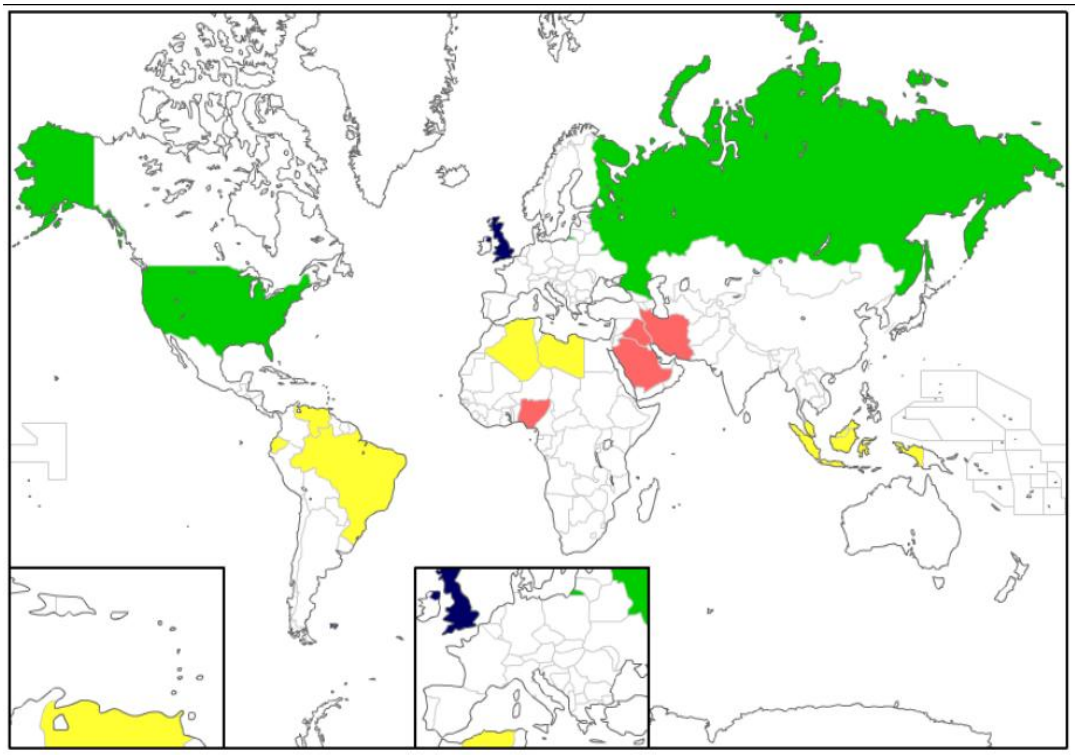
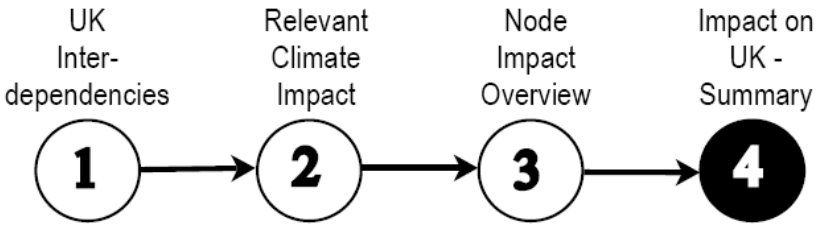


Figure 4.3.4 Countries contributing significantly to UK Energy Security.The regions marked in red are highly *vulnerable, those in yellow moderately vulnerable and those in green are considered reasonably resilient to any climate change impact.*

4.3.4 Impact on UK Energy - Summary



Ground mining and the extraction and distribution of petroleum and gas both have the potential to be affected by climate change. In the case of each of

these activities, climate change is unlikely to affect the security of supply in the long run, but could have a shorter term impact on the price.

Energy infrastructure, especially electricity, will be increasingly vulnerable to unanticipated severe weather events caused by changing climate patterns. This is likely to lead to a greater frequency of brownouts and supply disruptions for business. Impact of climate change on energy infrastructure in other parts of Western Europe may affect the UK since the European interconnnectors already draw on electricity from France.

Although in some regions water availability may become a limiting factor, or at least increase expense, most mining and extraction operations are already carried out in environmentally challenging areas. Commodity price determines whether the cost of extraction makes the endeavour worthwhile, and although climate change may marginally increase costs, the drivers of price are numerous and potentially a far more significant factor in this equation (Met Office 2010).

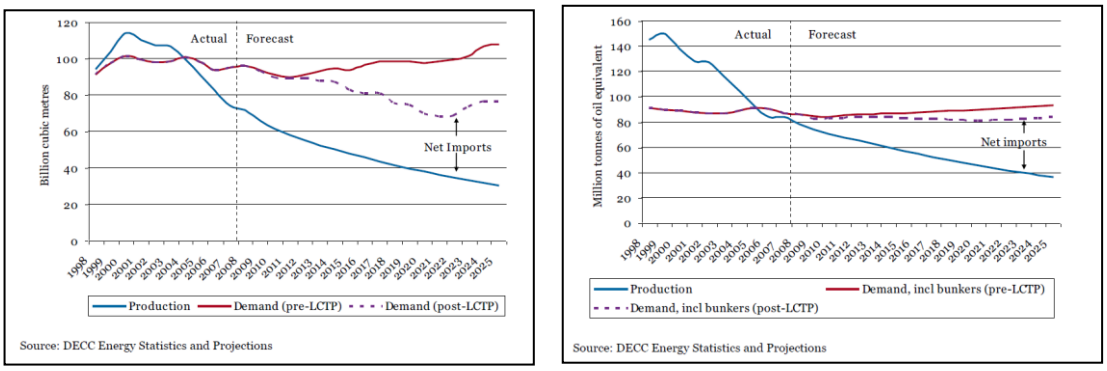


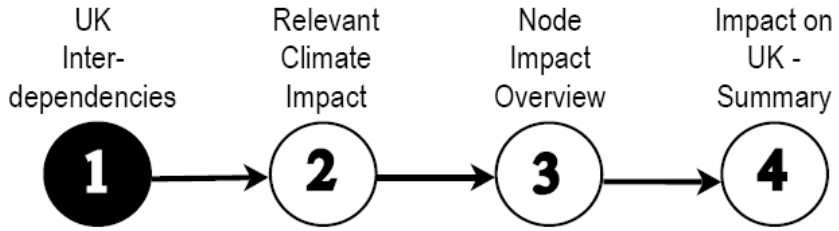
Figure 4.3.5 Projections of increasing importation of oil and gas (Wicks 2009)

The physical infrastructure of the energy sector is vulnerable to the potential flooding of facilities, damage to power lines and disruption to power stations. In common with most countries, the UK's energy capacity has evolved as a primarily centralized network which makes it highly dependent on a relatively inflexible system of critical infrastructural assets (Scottish Government 2009). The UK's exposure to energy supply risk is likely to increase as imported supply grows to fill the demand gaps as indicated in Figure 4.3.5.

4.4 Water Availability

Focus Question: how might the UK's dependence on embodied water in food imports be affected by climate change elsewhere?

4.4.1 UK Interdependencies



In terms of direct water vulnerability, the only significant area of the UK is SE England (UKCIP, 1999). For the most part the UK is well endowed with water, although weather variability can cause regional droughts and water scarcities. The extent and intensity of these droughts is relatively small, thus direct dependency on water supply from elsewhere is not a problem in the same sense as in those countries that share a major river for irrigation in arid areas or at times of seasonal drought, for example.

The world population has risen threefold within the lifetime of the post-war generation (2.5 billion to 7 billion) and is increasing remorselessly towards 9 billion. Supplying food for this rising population coupled with increasing urbanisation and burgeoning living standards has resulted in increased contamination and marked reduction in the volume of our global 'freshwater bank'. A potential global disaster brought about by the lack of clean water and proper sanitation is less than a generation away (Kalin 2008).

The water challenge for the UK stems from the recognition that we are indirectly very dependent on water availability elsewhere. The key concept to understand this is 'embodied water' also referred to as 'virtual water'. This is the water used in the production of goods or services. It is defined as "*the volume of freshwater used to produce the product, measured at the place where the product was actually produced*" (Hoekstra and Chapagain 2007).

Virtual water consumption can be massive for consumer goods we take for granted. For example it has been estimated that it takes 10,850 litres of water to produce one pair of blue jeans and 2,500 litres of water for a T-shirt. This 'embedded' water refers to the water it takes to produce the cotton, mine raw materials, knit and dye the fabric, etc. The main global trade in virtual water is through food including meat, grains, fresh produce, vegetables and fruit where the real-water content of each is negligible when compared to the virtual water content it took to grow (Kalin 2008). Many imported raw materials used in the construction and manufacturing industry also have high levels of embodied water, for example steel, cement, timber, and glass.

Another useful concept is 'water footprint' which is the total water resource depletion (local to global) that a given consumer is responsible for. The water footprint per person in poorer countries is around 800 cubic meters per year whereas that in developed countries is closer to 2500 cubic meters. Given that, for example, many exporting countries of high embodied water food and other products are water stressed, there is a structural basis for water issues to increase considerably exacerbated by climate change (Pacific Institute, 2009). Table 4.4.1 shows the water requirement of some main food products.

Unit Equivalent Water (litres per unit)		
Citrus Fruits	Kg	1,000
Cereals	Kg	1,500
Fresh Poultry	Kg	6,000
Fresh Beef	Kg	15,000
Sheep or Goats	Head	500,000
Cattle	Head	4,000,000

Table 4.4.1 - Water requirement of equivalent of main food products
Source: FAO 2003 UN World Water Development Report

Some of the kinds of foods imported into the UK where embodied or virtual water is significant are shown in Table 4.4.2.

Country of Origin	Produce
Spain / Portugal / Italy	Raspberries, grapes, tomatoes, cucumbers, radish, lettuce, oranges, rosemary, mint, onions, basil, courgettes, marrow, broccoli, pears, plums
Israel / West Bank / Bolivia / Peru / Argentina / Chile	Sharon fruit, figs, cherimoya, persimmon, pomelo, mango, dates, thyme, sage, chives, black grapes, avocado, limes, mango, cantaloupe, piel des apid, honeydew, brazil nuts, mange tout, asparagus, sugar beans
Uruguay / Costa Rica / Ecuador / Columbia	Pineapple, banana, mandarin oranges, tangerines, kiwi, physalis, passion fruit
USA / Mexico	Peaches, onions, butternut squash, grapefruit, walnuts, pecans, sweet potatoes, rocket, lettuce
Egypt / Morocco / Iran	Salad onion, pistachios, dates, string beans, green beans, runner beans
Kenya / Mozambique	Baby corn, mange tout, runner beans, peas, chili peppers,
South Africa	Red apples, Granny Smith apples, oranges, lemons, grapefruit, Pink Lady apples

Table 4.4.2 - Sources of fresh produce in Scottish supermarkets showing majority of popular items imported from water-scarce regions of the world. (Kalin 2008)

The external water footprint (EWF) of the UK is presented in figure 4.4.1. The arrow points in the figure show the major sources of the UK's external agricultural water footprint. Most of the products that make up the UK's EWF originate from Brazil, France, Ireland, Ghana and India. Ghana provides cocoa, which is mainly rainfed. Brazil provides soybeans, coffee, and livestock products, while France provides mainly seasonal produce. Ireland provides mainly meat products, and India, cotton, rice and tea.

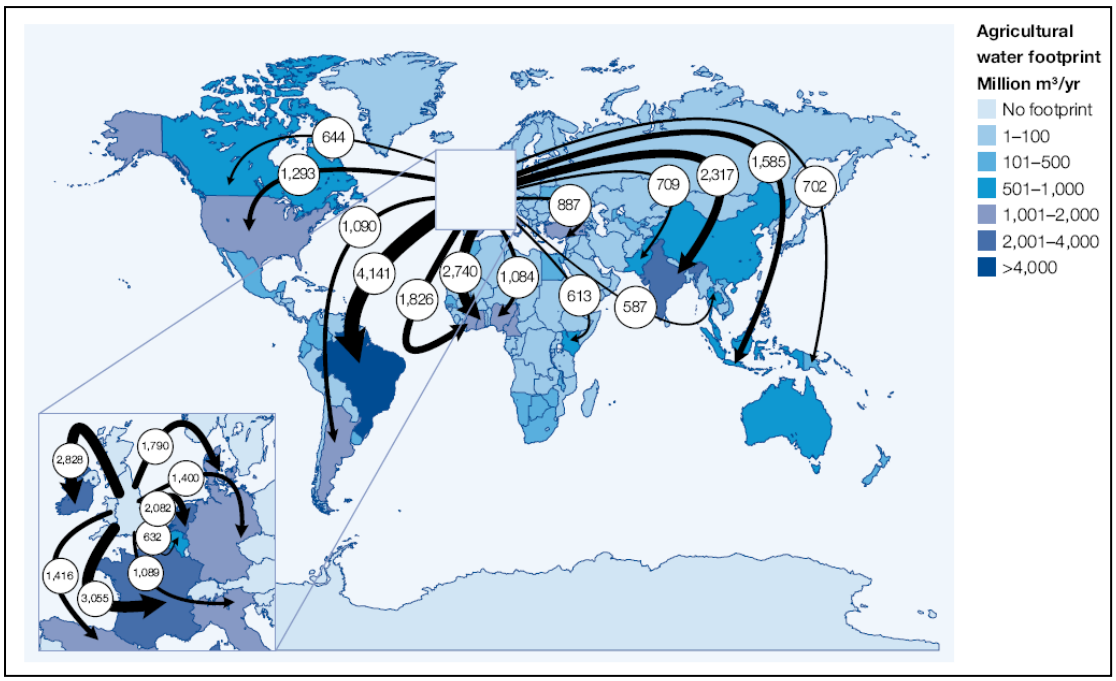


Figure 4.4.1 - The UK's external agricultural water footprint (Chapagain and Orr 2008)

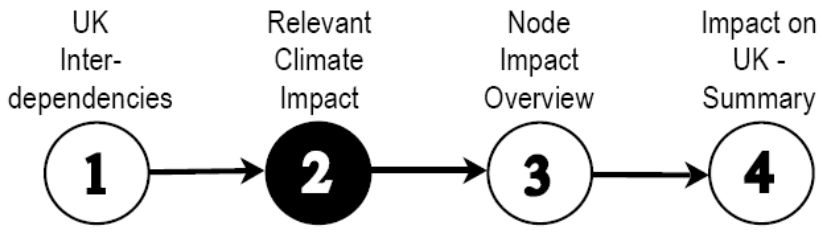
Figure4.4.2 – Map showing the main areas of the world from which the UK imports virtual water in agricultural products

Figure 4.4.2 and Table 4.4.2 detail the UK's major sources for importing virtual water and Table 4.4.3 the external agricultural water footprint for the UK.

Country / Region	Agricultural water footprint (million m^3 /yr)	Virtual Water
Western Europe (especially France and Spain)	14,292	High
Mid Africa (especially Ghana, Nigeria, Kenya)	6,2,63	High
Brazil	4,141	Medium
India (Indian SC)	2,317	Medium
SE Asia	1,585	Lower
United States	1,293	Lower
Argentina (Andean S America)	1,090	Lower

Table 4.4.3 - The UK's external agricultural water footprint (Chapagain and Orr 2008)

4.4.2 Relevant Climate Impact



There follows a note on each of the main countries and regions highlighted in the map Fig 4.4.2 . The points made are extracted from the World Stories in Book 2 Section 1.

Western Europe

High use of embodied water; Low vulnerability

- Problems related to public water and drinking water will be exacerbated all over Europe with particular hotspots in the Mediterranean.
- More frequent droughts, with considerable impacts on agriculture and water resources.
- Water scarcity around the Mediterranean will affect agricultural productivity and change the cultural identity of certain regions.
- Current rate of glacier retreat in the Alps is reaching levels exceeding those of the past 5000 years.

Note: It is important to consider Spain as a special case since its current climate is already more exposed to water shortage and yet it exports a great deal of produce with high virtual water. “In Spain the water footprint of agriculture and livestock production accounts for almost 80% of national water footprint. Results indicate that Spain is a water footprint “importer” in the form of primary crops, but a water footprint “exporter” in livestock terms” (Novo et al 2009).

Mid Africa

Medium use of embodied water; High vulnerability

- 69% of the population lives under conditions of relative water abundance
- The rainy season centers around late northern hemisphere summer, at which time the amount of rainfall will determine whether drought or good harvest conditions will prevail for the following year.
- There are issues around the extent to which that water is potable and accessible, and the availability of sanitation

Brazil

Medium virtual water; Medium vulnerability

- Accelerated urban growth, increasing poverty and low investment in water supply will contribute to: water shortages in many cities; high percentages of the urban population without access to sanitation services; an absence of treatment plants; high groundwater pollution; lack of urban drainage systems; storm sewers used for domestic waste disposal; the occupation of flood valleys during drought seasons; and high impacts during flood seasons.
- Bacterial infection from contaminated water will possibly increase in the future as heavy rainfall and rising temperatures, as well as increased incidences of toxic algal blooms, lead to pollution of recreational waters and increased need for treatment of potable water.

Note: Brazil's economy has been growing steadily over the last few years, a trend that is likely to continue. The revenues from oil and gas exports may finance infrastructure improvements that could increase adaptive capacity and decrease vulnerability in Brazil.

India

Medium embodied water use; High vulnerability

- Beyond 2050, water demand will exceed supply
- The bulk of Indian agriculture not only remains rain-fed but also depends on groundwater, not surface water
- Drinking water shortages and increases in food and biomass fuel prices
- Reduced river flows and increased water temperature will lead to declining water quality
- More severe storms (especially cyclones) are predicted due to climate change

- Salt water intrusion during storm surges will lead to salination and loss of agricultural land in coastal regions
- As river flows decline and the frequency of more severe droughts and floods increases, water disputes between Indian states and with neighbouring nations (eg: Pakistan, Bangladesh, and Nepal) will increase.

SE Asia

Medium embodied water use; Medium vulnerability

- Individual areas under severe water stress in the region are projected to increase dramatically in the next few decades
- Much of South East Asia's water supply and water quality are sensitive to small changes in the frequency and distribution of precipitation. Recent changes in precipitation patterns have already been linked to increases in runoff, erosion, flooding, and associated impacts on surface water and groundwater
- Freshwater resources on all island nations in the region are especially vulnerable to any variability in precipitation patterns because many rely on rainwater collection for their supply of freshwater. The management of water issues is one of the most challenging climate-related issues in the region, as it is central to health and sustainable development.

United States

Medium embodied water use; Low vulnerability

- The impacts of climate change include too little water (droughts) in some places, too much water (floods) in other places, and degraded water quality in many places
- Changes in precipitation, temperature, humidity, salinity, and wind have a measurable effect on water quality recharge and transport of water into the aquifers

- Climate change will very likely exacerbate competition in regions where freshwater availability is reduced by increased evaporation due to rising air temperatures and changes in precipitation
- The natural ecosystems of arctic Alaska, the Great Lakes, the Great Basin, the Southeast, and the prairies of the Great Plains are considered highly vulnerable to the projected changes in climate
- Changes in the water cycle are expected to continue and to adversely affect energy production and use, human health, transportation, agriculture, and ecosystems
- Energy production is likely to be constrained by rising temperatures and limited water supplies in many regions. Coal, oil, nuclear, and many natural gas power plants rely on massive amounts of water.

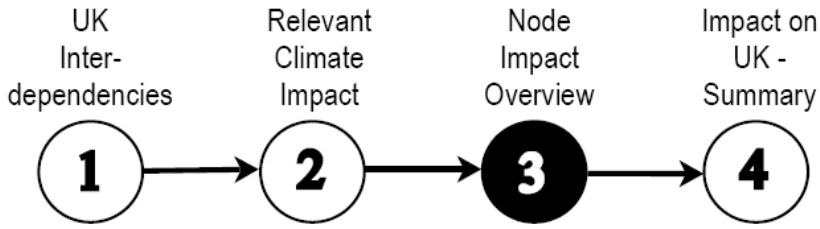
Andean South America (especially Argentina)

Lower embodied water use; Medium vulnerability

In global terms, Latin America is recognised as a region with large freshwater resources. However, the irregular temporal and spatial distribution of these resources affects their availability and quality in different regions.

As a consequence of temperature increases, the trend in glacier retreat is accelerating. This issue is critical in Bolivia, Peru, Colombia and Ecuador, where water availability has already compromised consumption and the rate of hydropower generation due to low river flows. These problems with supply are expected to increase in the future, becoming chronic if no appropriate adaptation measures are planned and implemented. Over the next decades Andean inter-tropical glaciers are very likely to disappear, affecting water availability.

4.4.3 Water Availability Overview



Despite being a water rich country the UK has invisible dependency on the imported water contained in imported foodstuffs, some of which come from water stressed countries. Climate change impact there, for example prolonged drought, could disrupt those supplies and affect aspects of food security.

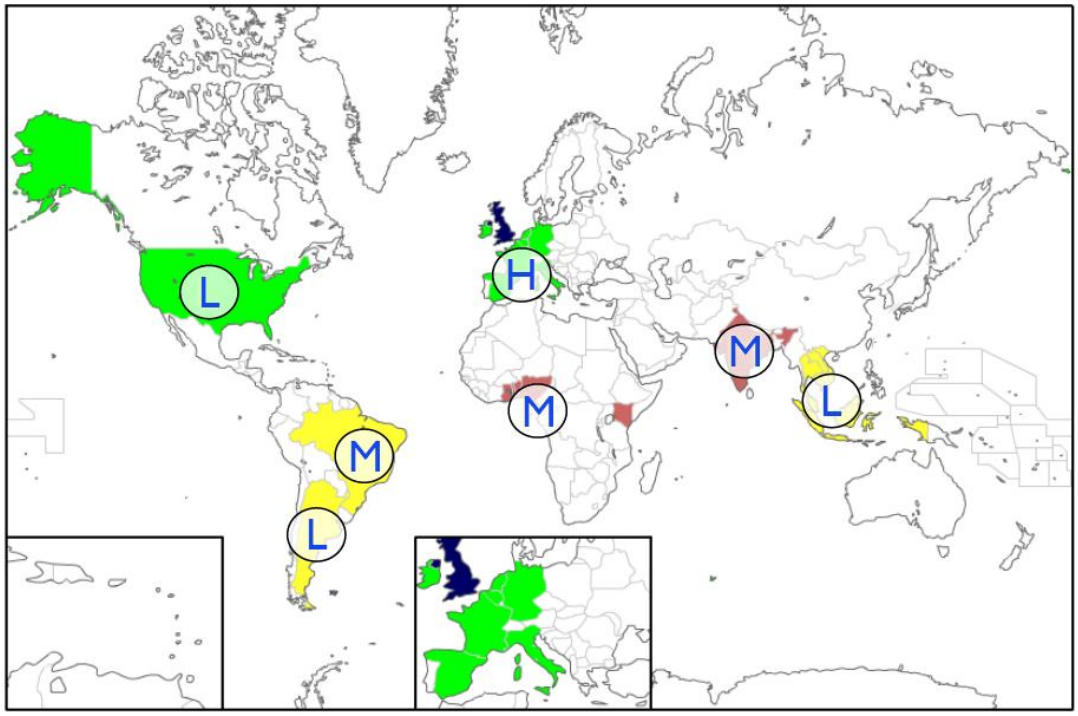
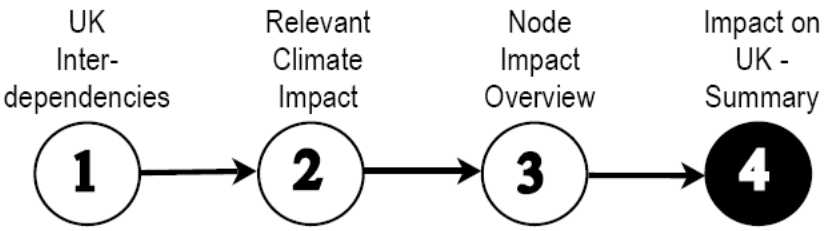


Figure 4.5 - Based on the above analysis, the map shows those regions upon which the UK depends. Relatively high dependence is marked H, medium dependence tare marked M, and those marked L are lower dependence. The regions marked in red are highly vulnerable, those in yellow moderately vulnerable and those in green are considered reasonably resilient to any climate change impact.

This analysis has concentrated on embodied water in relation to food. Further study and compilation is needed of any additional research into the embodied water in extracting raw materials, in manufactured goods and in the creation and maintenance of infrastructure.



4.4.4 Impact on the UK Water Availability - Summary

Water availability can have an effect on international trade which is often overlooked. Countries with more water are able to trade water-intensive goods for export. Water used to grow or produce traded crops or goods has been termed 'embodied water' or 'virtual water'. Embodied water trade has been suggested as a way to alleviate water shortages. While this offers the potential to help mitigate water scarcity risks, it should be recognized that most trade is not based on rational determinations of comparative advantage based on water, but rather on broader political and economic factors (Orr et al 2009).

The *water footprint* concept has been developed to illustrate the hidden links between human consumption and water use and between global trade and water resources management. Water resources management is generally seen as a local issue or a river basin issue. The global aspect of water resources management has been overlooked by most of the water science and policy community. In addition, "*the production (supply) perspective in water resources management is so dominant that it is hardly recognised that water use relates in the end to levels of all human consumption not just water. The water footprint concept has primarily been introduced in the water science community in order to demonstrate that both a consumer dimension*

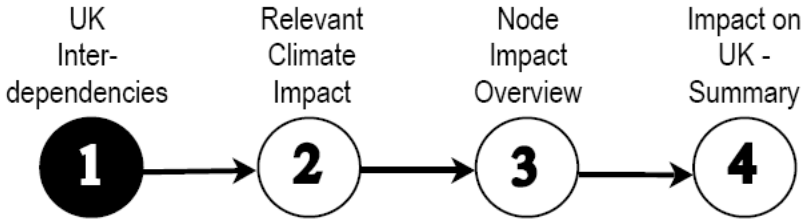
and a global dimension should be added in considerations of good water governance " (Hoekstra 2008).

The risk to the UK of embodied water is that it remains largely unrecognised and thus leaves food imports, manufactured goods and basic materials, such as steel, vulnerable to water scarcity elsewhere. (UNWater 2009)

4.5 Habitat and Infrastructure Dependencies

Focus Question: where is the UK's global trading infrastructure vulnerable to climate change impacts elsewhere?

4.5.1 UK Interdependencies



As a trading nation the UK is deeply dependent on cities worldwide. Their economic productivity is central to sustaining the scale of UK trade. It is estimated by the UN that by 2030 nearly 60% of the world's people will be urban dwellers out of a global population of around 7-8 billion. The fate of cities around the world, particularly in their role as major export markets and sources of key imports, is inextricably tied to the fortunes of the UK. Thus the impact of climate change on the world's cities will have repercussions for the UK. Climate change has the potential to adversely affect most of the major shipping ports and to disrupt major trading routes, with potentially severe consequences for the global and hence the UK economy.

The world has witnessed in recent years some of the socio-economic challenges associated with global warming and climate change. The rise in prices of fuel and food has provoked angry reactions worldwide and threatens to eradicate, in many instances, decades of social and economic advancement. This relatively new threat to harmonious urban development is nonetheless directly linked to poorly planned and managed urbanization (UN-HABITAT 2008).

As far as trade is concerned, port cities are the most significant and potentially vulnerable. In a screening study of 136 cities with populations of more than one million, an OECD analysis shows that several trading centres in

developed countries are at risk. The top 10 cities in terms of assets exposed are Miami, Greater New York, New Orleans, Osaka-Kobe, Tokyo, Amsterdam, Rotterdam, Nagoya, Tampa-St Petersburg and Virginia Beach. These cities contain 60% of the total exposure, but are from only three (wealthy) countries: USA, Japan and the Netherlands. The total value of assets exposed in 2005 across all cities considered here is estimated to be US$3,000 billion; corresponding to around 5% of global GDP in 2005 (both measured in international USD) (Nicholls et al 2007).

It must be emphasised that exposure does not necessarily translate into impact. The linkage between exposure and the residual risk of impact depends upon flood (and wind) protection measures. In general, cities in richer countries have higher protection levels than those in the developing world. Exposed populations and assets remain dependent on protection that can fail. Hence, even assuming that protection levels will be very high everywhere in the future, the large exposure in terms of population and assets (See Fig 4.5.1) is likely to translate into regular city-scale disasters across the globe. The policy implications of this report are clear: the benefits of climate change policies – both global mitigation and local adaptation at the city-scale – are potentially great. (Nicholls et al 2007)

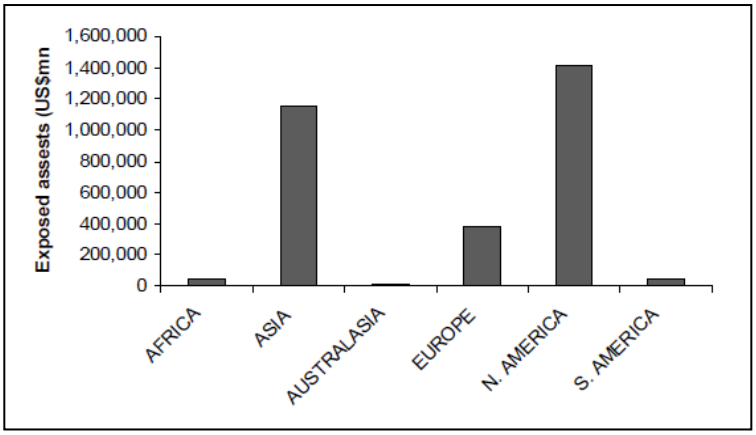


Fig 4.5.1 - Total assets currently exposed to extreme (high) water levels by continent (Nicholls et al 2007). This chart considers high water marks due to floods and storm surges and does not include predictions of sea-level rise due to climate change.

The impact on the UK from climate impact on infrastructure elsewhere is mediated through the way such impacts could disrupt the economy and hence have knock-on effects to the UK, defined as Category 1 in the introduction to this section. The map (Fig 4.5.2) showing the web of shipping and energy transport routes gives some indication of the global system open to disruption from weather and climate change events.

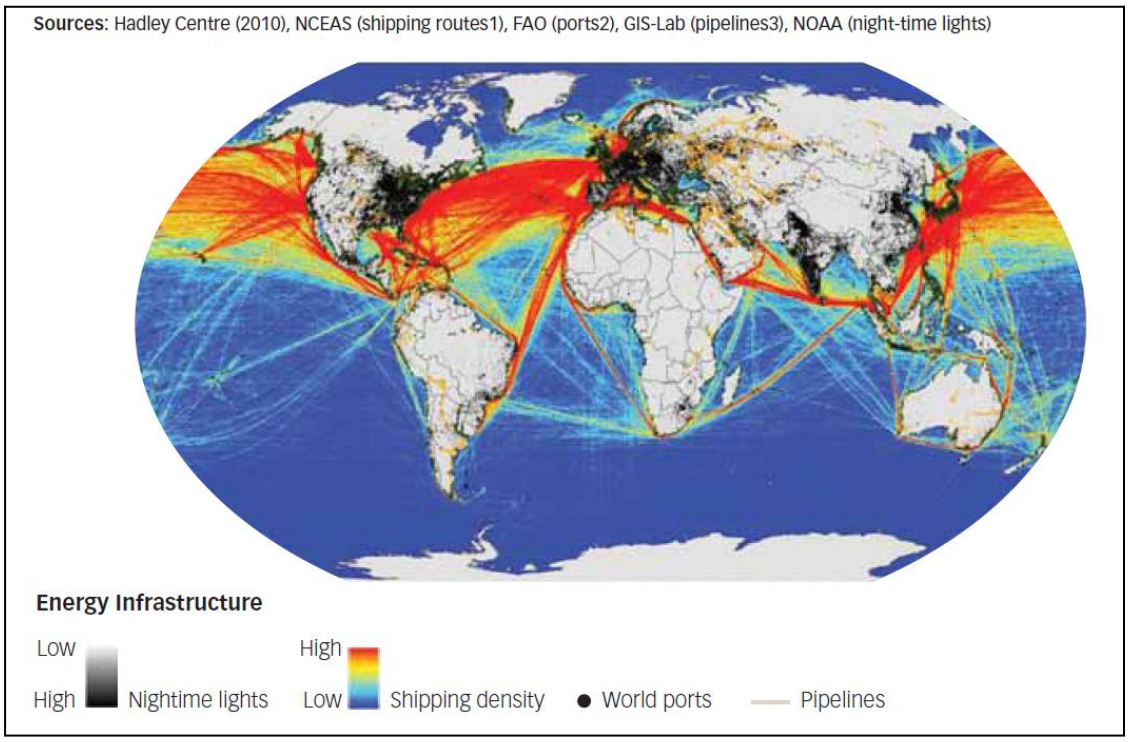
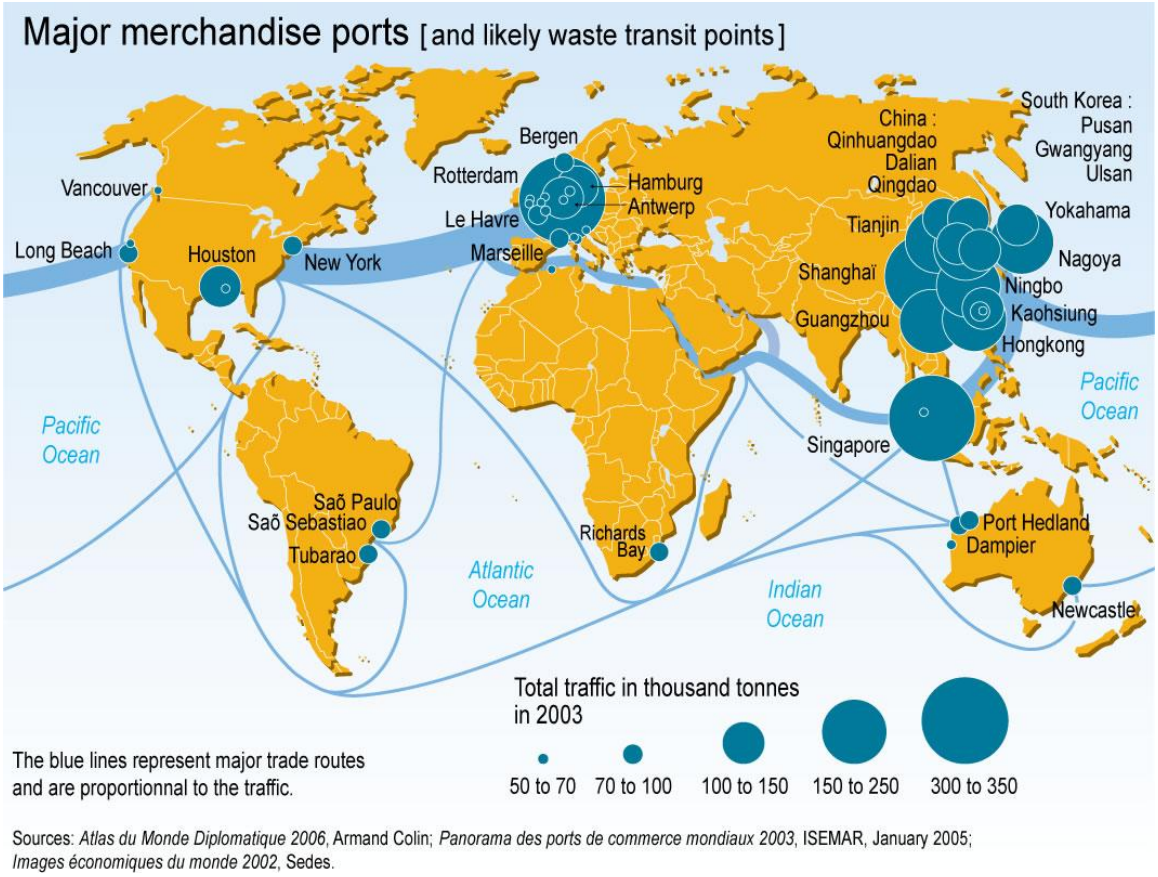


Figure 4.5.2 – Map showing *energy and trade interdependence (Hadley Centre 2010)*

The next map Figure 4.5.3 indicates where the major ports are located in the world, the major trade routes and the scale of traffic between them.



Sources: *Atlas du Monde Diplomatique 2006*, Armand Colin; *Panorama des ports de commerce mondiaux 2003*, ISEMAR, January 2005; *Images économiques du monde 2002*, Sedes.

Figure 4.5.3 -Map showing the major merchandise ports and the main trade routes that could be subject to climate change impacts. (Atlas du Monde Diplomatique 2006)

The analysis that follows takes a sample of twelve top trading ports in terms of container shipping and ranks them according to the OECD analysis in terms of exposed assets. Such a list may serve as a rough proxy for the potential disruption to trade capability due to severe weather events and storm surges. The effect of such disruption would significantly impact on world trade and thus the UK economy.

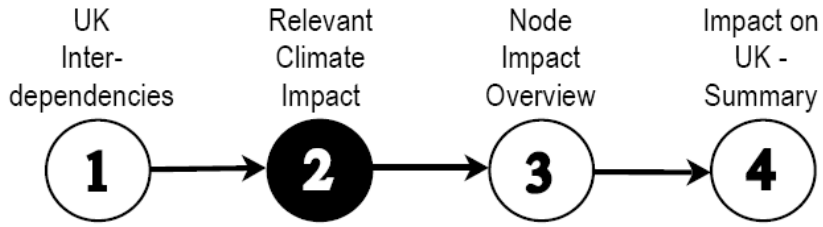
Size Ranking	Country	Port	Scale (2007)	Vulnerability Ranking (★)	Impact Rating
11	China	Guangzhou	9200	2	High
2	China	Shanghai	26150	5	High
3	China	Hong Kong	23881	9	High
10	China	Ningbo	9349	11	High
6	Netherlands	Rotterdam	10791	15	High
9	China	Quingdao	9462	18	Medium
7	UAE	Dubai	10653	24	Medium
4	China	Shenzhen	21099	32	Medium
8	Germany	Hamburg	9890	44	Medium
12	USA	Los Angeles	8355	45	Medium
5	South Korea	Busan	13270	70	Lower
1	Singapore	Singapore	27932	79	Lower

Table 4.5.1 - Container traffic in thousands TEU (Source: Nomura Securities - The New Spice Route) http://www.ritholtz.com/blog/2009/08/worlds-busiest-ports . Vulnerability ranking from Nicholls et al 2007.

The following map shows the main areas of infrastructure vulnerability that might have repercussions for the UK. Clearly, disruptions to ports in other regions of the world would also impact UK trade but a detailed analysis of UK trade dependencies is beyond the scope of this analysis..

Figure 4.5.4 - Map showing areas of greatest potential disruption to global trade from climate change effects on the global transport of goods

4.5.2 Relevant Climate Impact



There follows a note on each of the main countries and regions highlighted in the map Fig 4.5.4. The points made are extracted from the World Stories in Book 2 Section 1.

China

Most crucial vulnerable ports: Guangzhou, Shanghai, Hong Kong, Ningbo, Qingdao and Shenzhen

- Due to their flat and low landscape, China's coastal regions, the engine of China's economic achievement, are highly vulnerable to storm, flood, and sea-level rise. The increasing frequency and intensity of extreme weather events such as typhoons has threatened economic development at local, regional, and national levels.
- It is likely that the weather events that different types of infrastructure (eg: ports, airports, bridges, dams, roads, powerplants, and sites of industrial production) are built to withstand will occur more regularly, and that more intense events will also increase in frequency, putting many types of infrastructure at significant risk by the middle of the 21st century.

SE Asia

Most crucial vulnerable ports: Singapore, Bangkok, Manila, Tai Pei, Ho Chi Min City, Kuala Lumpur, Jakarta.

- Increases in sea level associated with climate change are particularly problematic for Southeast Asia, which is comprised of low-lying coastal

and island nations. In fact, approximately 20 percent of the world's population of low-lying coastal regions is in Southeast Asia.

- The megadeltas of Asia are vulnerable to climate change and sea level rise. This impact could be more pronounced in megacities located in megadeltas where natural ground subsidence is enhanced by human activities.
- Densely settled and intensively used low-lying coastal plains, islands, and deltas are especially vulnerable to coastal erosion and land loss, inundation and sea flooding, upstream movement of the saline/freshwater front, and seawater intrusion into freshwater lenses. Especially at risk are the large deltaic regions of Bangladesh, Myanmar, Vietnam, and Thailand, and the low-lying areas of Indonesia, the Philippines, and Malaysia.

The map in Figure 4.5.5 shows those coastal cities in Asia vulnerable if there is significant sea level rise.

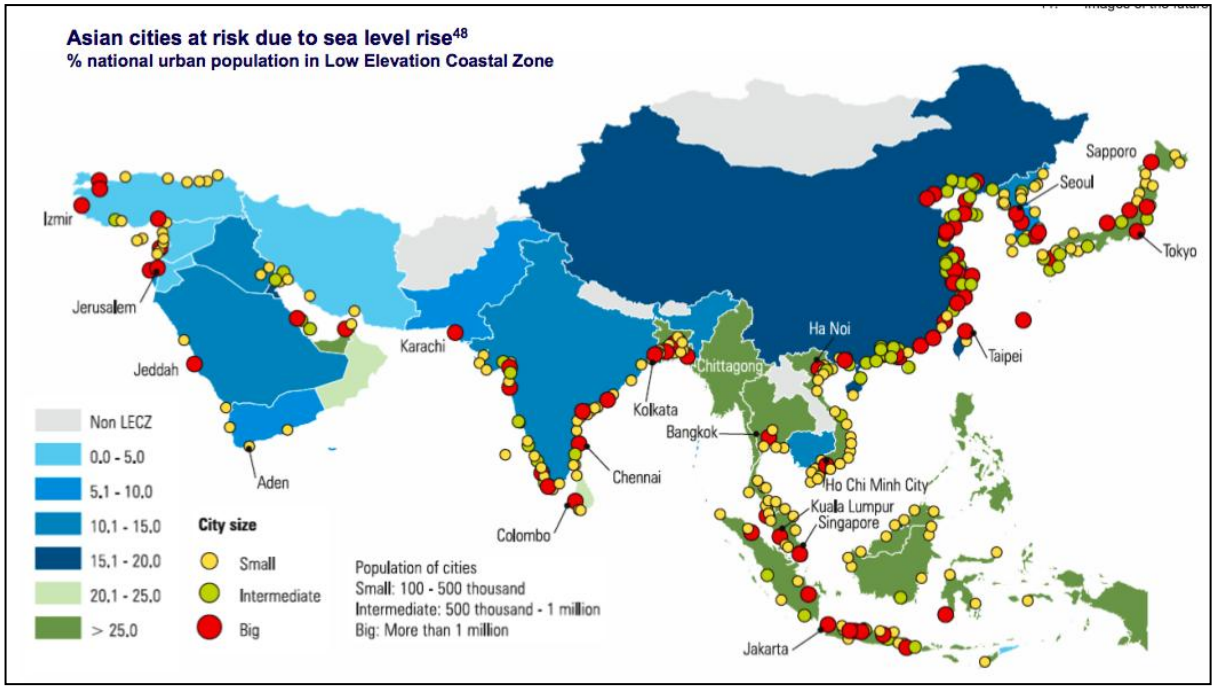


Figure 4.5.5 - Asian cities at risk from sea level rise (UNHABITAT 2009)

Western Europe

Most crucial vulnerable ports: Rotterdam and Hamburg

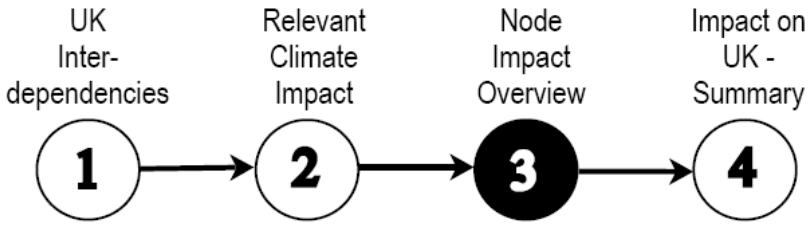
- Weather-related disasters or extremes are projected to increase all over Europe
- Northern Europe is likely to have fewer damages, while Central Europe and the British Isles would undergo significant increases in expected damages.

United States

Most crucial vulnerable ports: Los Angeles/Long Beach

- New York City, for example, could experience what are now considered 100-year floods every three to four years by the end of the 21st century, while strong storm surges could easily inundate much of the energy grids and other small-scale infrastructure in Washington D.C.
- With much of the state and Miami at near sea-level, Florida's infrastructure is particularly vulnerable to climate change impacts. The same holds for all the US coastline along the Gulf of Mexico.
- The recent natural disasters of Hurricanes Katrina, Rita and Wilma (all in 2005), highlighted just how susceptible the US's infrastructure can be. Increasing populations and further development on coastal areas will continue to put pressure on vulnerable infrastructure
- The most significant climate impacts to California's infrastructure are predicted to be from higher temperatures, forest fires, and extreme weather events across the state, reduced and shifting precipitation patterns in Northern California, and sea-level rise.

4.5.3 Habitat and Infrastructure Overview



Climate change impacts and climate vulnerability in other parts of the world do not have a direct impact on UK infrastructure. However, there are coastal zones of high trade volume (containers) where the condition of the infrastructure (eg the ability to load and unload cargo containers) relates directly to the UK's ability to export and import goods. Disruption of port infrastructures elsewhere could lead to clogging of UK infrastructure due to inability of foreign ports to receive UK exports. Conversely, a short or long term inability of certain foreign ports to export would place the stress of large shortfalls on UK imports. The map in Figure 4.5.6 shows the areas of largest shipping activity and their corresponding climate impact vulnerability.

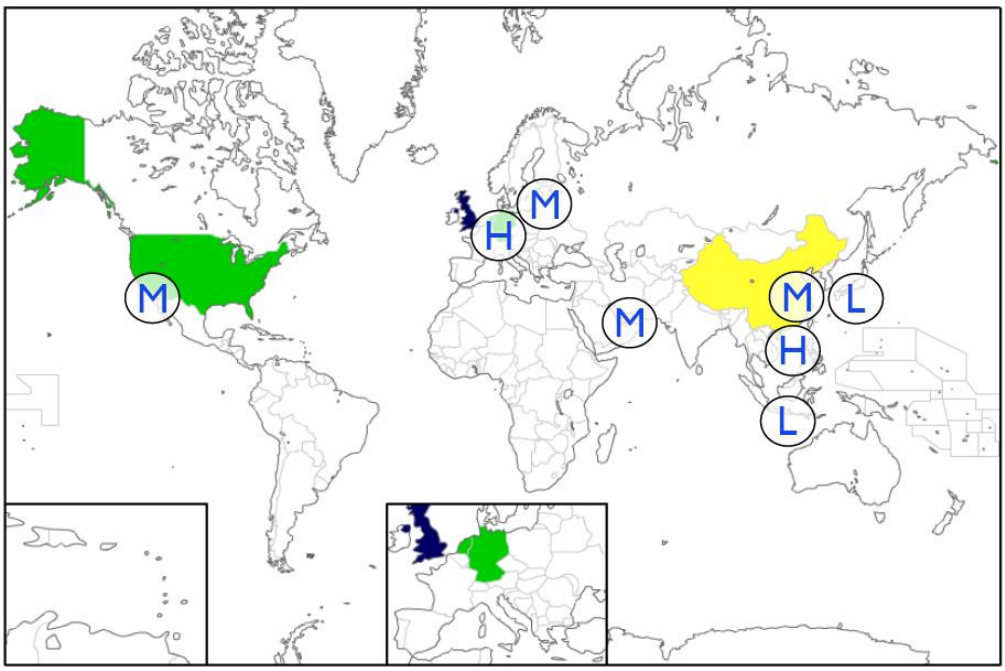
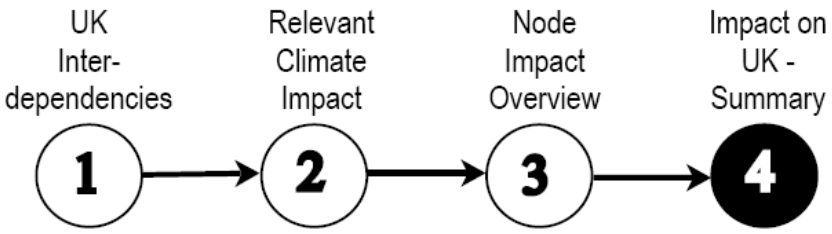


Figure 4.5.6 - Areas of greatest volume of container trade and their exposure to asset damage from climate events

.

4.5.4 Impact on UK Habitat and Infrastructure - Summary



We are living in an increasingly interconnected world due to economic globalization and trade, as well as advances in information technologies, resource scarcity, and increased mobility between countries, to name just a few drivers of this interdependence. It can safely be assumed that adverse impact of climate change on key infrastructures in one country or region will affect other countries or regions worldwide, including the UK. Such impacts could potentially generate negative (or perhaps positive) effects that could differ in kind and from region to region. Future studies that seek to gain a better understanding of the potential impact of impact, will continue to be challenged by the high levels of complexity and uncertainty that such in depth exploration entails.

The initial analysis offered here shows that the low elevation coastal zones concentrate people, economic activity and resulting infrastructure, so the impacts of climate change and sea-level rise could be large, especially if the magnitude of change is large. This will be exacerbated by coastal development, an intensifying trend that is likely to continue throughout this century. Nevertheless, effective adaptation could help to minimise potential impacts. Since assessing the future in the face of complexity and uncertainty cannot be an exact science with undisputable quantitative data, this study has taken a more qualitative approach for the assessment of both threats and opportunities for the UK.

Some of the potential threats include:

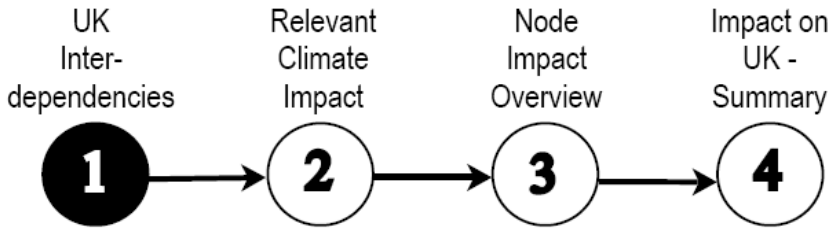
- Disruption of supply chains by more frequent coastal disasters such as occurred to the oil supply after Hurricane Katrina in 2005;

- Security threats due to forced population movements possibly leading to significant numbers of refugees and migrants and broader security issues in important parts of the world;
- A decline in UK prestige, as the UK, along with other developed nations, is blamed erroneously for all coastal disasters which are increasingly seen as a product of human-induced climate change rather than climate variability;
- Direct and indirect impacts on the UK finance, business and insurance industry;
- Potential impacts on the UK's overseas small island state territories.

4.5 Economy and Wealth Dependencies

Focus Question: how is the UK's financial sector vulnerable to climate change impacts elsewhere?

4.5.1 UK Interdependencies



Climate change impact elsewhere has powerful implications for the UK economy and the wealth of its society and citizens especially in the aspect of employment. Economic disruption results in job losses. However, the secondary impact tends to be of the type category 1 (see introduction to this section) in that it is mediated through the global economic and financial system. This mediation operates in two ways; climate change can affect the markets to which the UK offers services and it can – over time - erode and even disrupt the structure of the market. This would lead to a category 2 impact challenge. Multiple catastrophic consequences of climate change elsewhere could lead to elimination of some markets as we know them.

Changes in the ability of insurance, banking and investment to perform in an international setting of climate change could be expected to have significant impacts on the UK economy, employment and the comparative advantage of the UK economy (Silver *et al*, 2010).

A difficulty in considering potential impacts on the UK is that the infrastructure and processes of global financial management operate on very short time scales mediated by the International Trade Commission (ITC) whereas the emergence of significant climate change impacts may be on a cycle of fifty to a hundred years. Furthermore a distinction has to be made between the

global cumulative impact of climate change impacts in many regions, and the impact of unpredictable severe weather events in one particular region, which can have either direct impacts on the UK economy (e.g. direct trade dependencies) or indirect impacts on the UK through consequences for the global economy. However, these difficulties can be addressed to some degree by considering overseas exposure of UK financial services. This exposure can be classified as primary, secondary and tertiary, as Silver *et al.* (2010) have done in Figure 4.6.1 below.

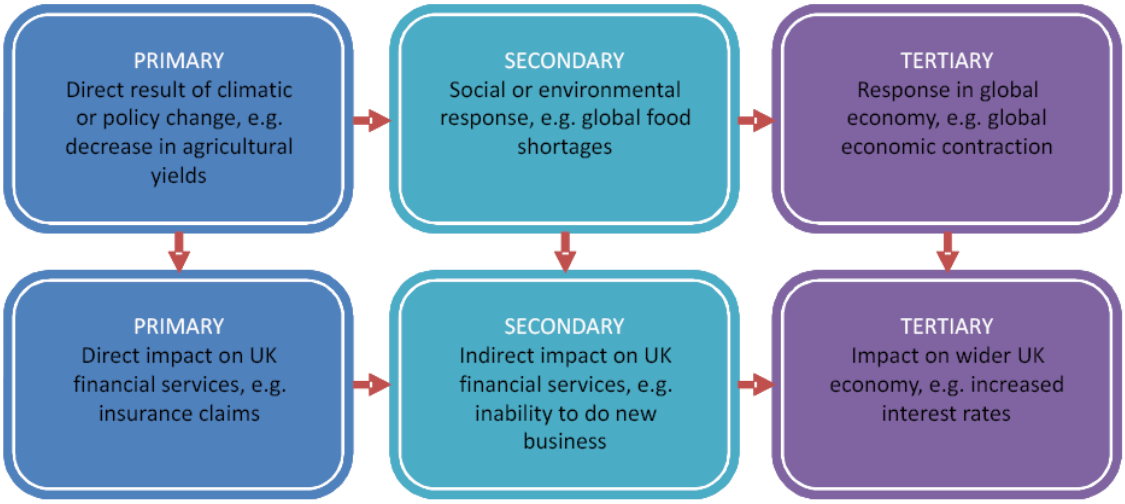


Figure 4.6.1 - Interlinking pathways of primary, secondary and tertiary impacts (Silver et al*, 2010)*

Primary impacts are direct climatic or social developments and the financial implications that result directly from them. Secondary impacts occur on a regional and possibly global scale, resulting from regional scale responses to climatic developments and the responses of the global economy to large scale disruption of climatic and social systems.

Tertiary impacts describe the phenomenon of global socio-economic feedbacks causing unrelated impacts on the UK financial system through, for example, interest rates and inflation.

The assets and investment of the UK abroad are not constants as the graph in Figure 4.6.2 shows. Furthermore, the value of UK investments abroad is subject to oscillations of the global economic system.

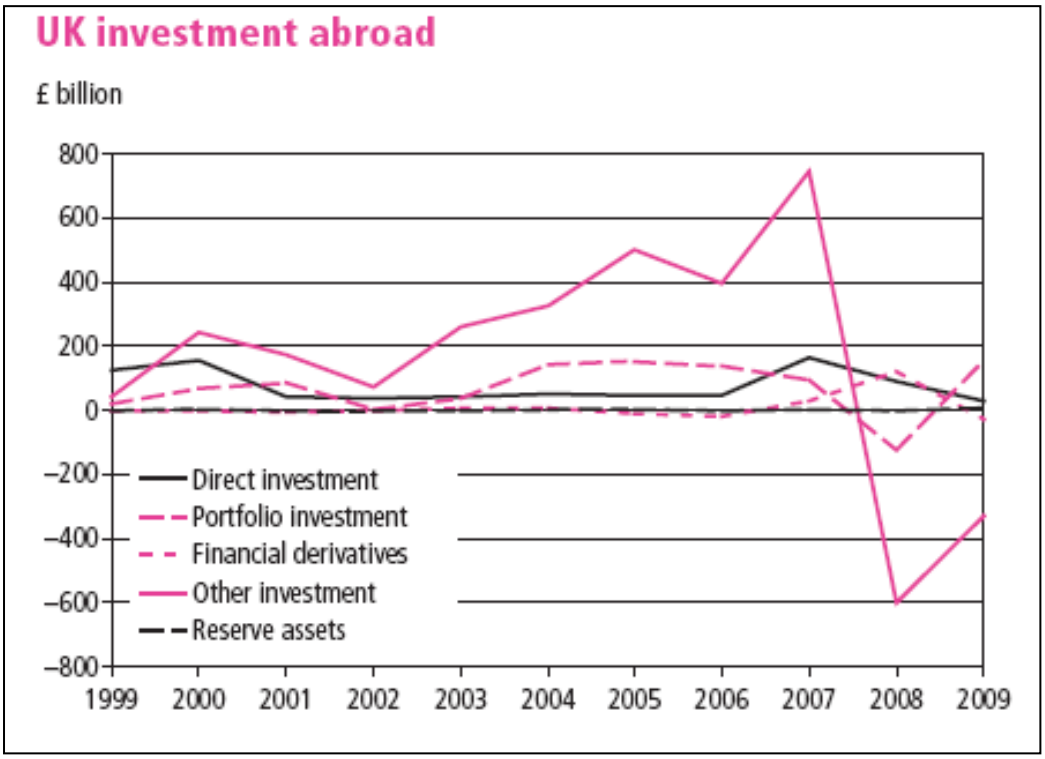


Fig 4.6.2 - Flows of UK investment abroad over the last ten years (Office for National Statistics 2010)

Direct investment assets have more than doubled over the last decade, to reach £1.0 trillion in 2009, after a record high at the end of 2008. (See Figure 4.6.3) Investments by the UK's private non-financial corporations (PNFCs') accounted for 74 per cent of UK direct investment assets at the end of 2009, while monetary financial institutions accounted for only 7.6 per cent and other financial intermediaries for a further 7.5 per cent. The value of PNFCs' assets almost trebled between 1997 and 2000, reflecting the substantial foreign acquisitions by UK oil and telecommunications companies in that period. Since 2000, the value of PNFCs' assets has generally continued to rise, however the level of stocks fell from £799.9 billion in 2008 to £760.4 billion in 2009 (Office for National Statistics 2010).

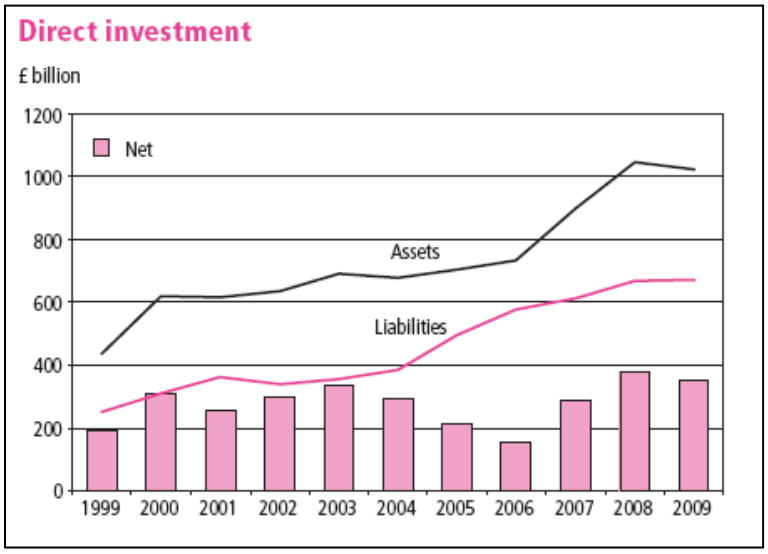


Fig 4.6.3 - Direct investment by the UK (Office for National Statistics 2010)

In order to get an indication of how potential climate impact on assets elsewhere could affect the UK, it is useful to take a closer look at a breakdown of where in the world the UK's PNFCs and financial institutions are most heavily invested and to compare this data with the level of vulnerability to climate impacts in those regions. It can be seen from the following chart in Figure 4.6.4 that the highest regional exposure in terms of credit and debit is in Europe, the USA and Asia.

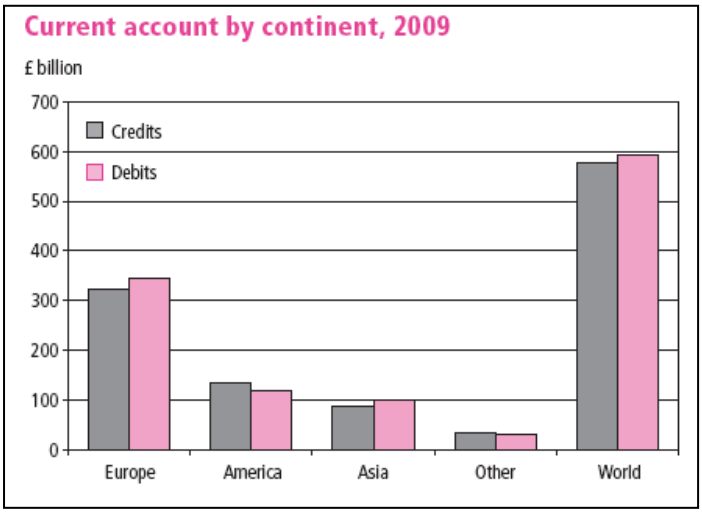


Figure 4.6.4 – Distribution of current accounts by continent (Office for National Statistics 2010)

It can be seen from Figure 4.6.5 that the outward investment exposure is somewhat higher in OECD countries, with the highest exposure being the EC and North America.

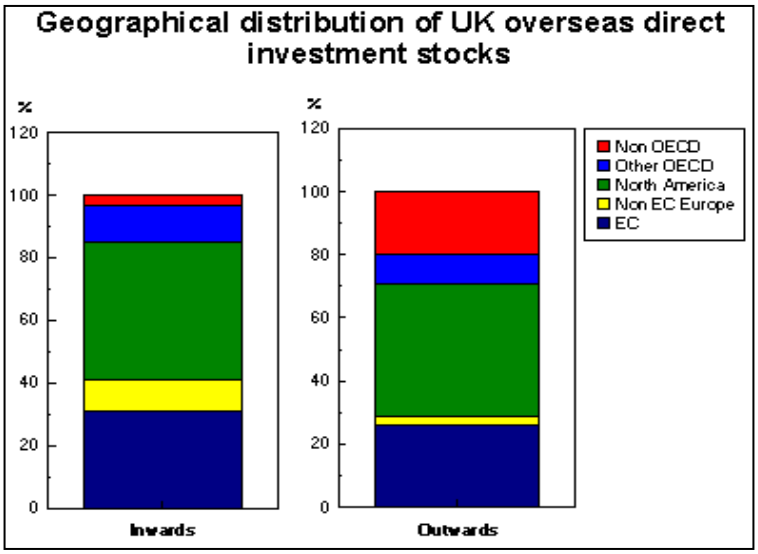


Fig 4.6.5 - Geographical distribution of UK 's investment stocks elsewhere (HM Treasury 2010)

Another perspective is provided by looking at the top five current account surpluses as shown in Figure 4.6.6.

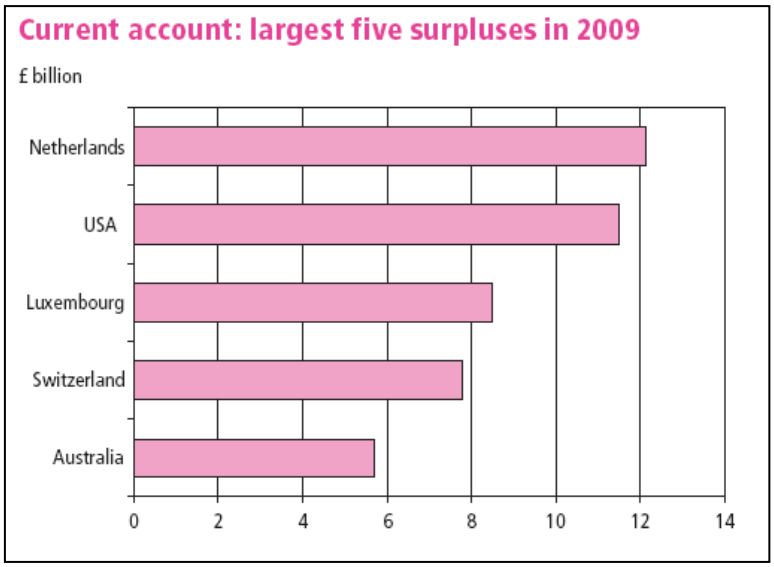
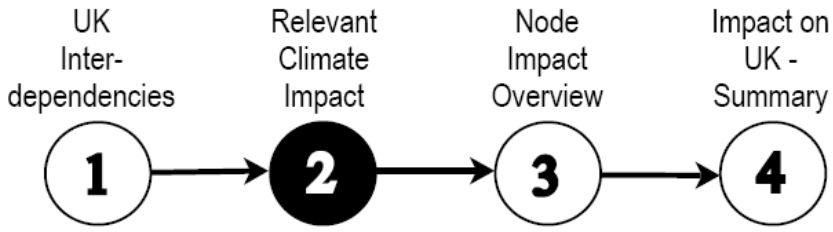


Figure 4.6.6 – The largest five surpluses of UK current account in 2009 (Office for National Statistics 2010)

4.6.2 Relevant Climate Impact



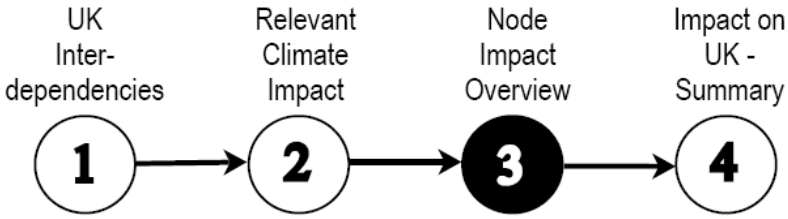
The information available does not enable a wide region by region breakdown but some clear observations emerge from the analysis. Firstly, the UK is far more heavily involved in terms of financial business and investment assets in the developed nations. Significantly, this is where there is more exposure to climate change impacts. However, these regions are generally in areas of lower vulnerability to direct impact (with perhaps the notable exception of US agriculture). Silver *et al.* (2010) offer the following general observations:

- The current strength of UK financial services to manage climate change risks and capture climate change opportunities relates to the distinctiveness of UK financial services
- The potential climate change vulnerabilities of UK financial services relate to system-wide characteristics of the global financial service system
- Structural vulnerabilities of the present financial service system increase exposure
- The sector's short-term view of sustainability is incompatible with the kind of multi-decade perspectives of change
- The scope of data considered by the sector to have financial relevance affects response
- Assumptions pervasive to financial services affecting its attention to and interpretation of climate change interactions affects response

As an illustrative example, the potential for the UK financial services industry to be affected by climatic and social impacts occurring in India is dependent on both direct exposure (UK financial and non-financial services operating in India) and indirect exposure through the global market. A changing monsoon

and resulting drought, food scarcity and regional conflict, can impact the UK financial sector (Silver et al 2010).

4.6.3 Economy and Wealth Overview



The map in figure 4.6.7 shows the basic world region vulnerability to the impact of climate change.

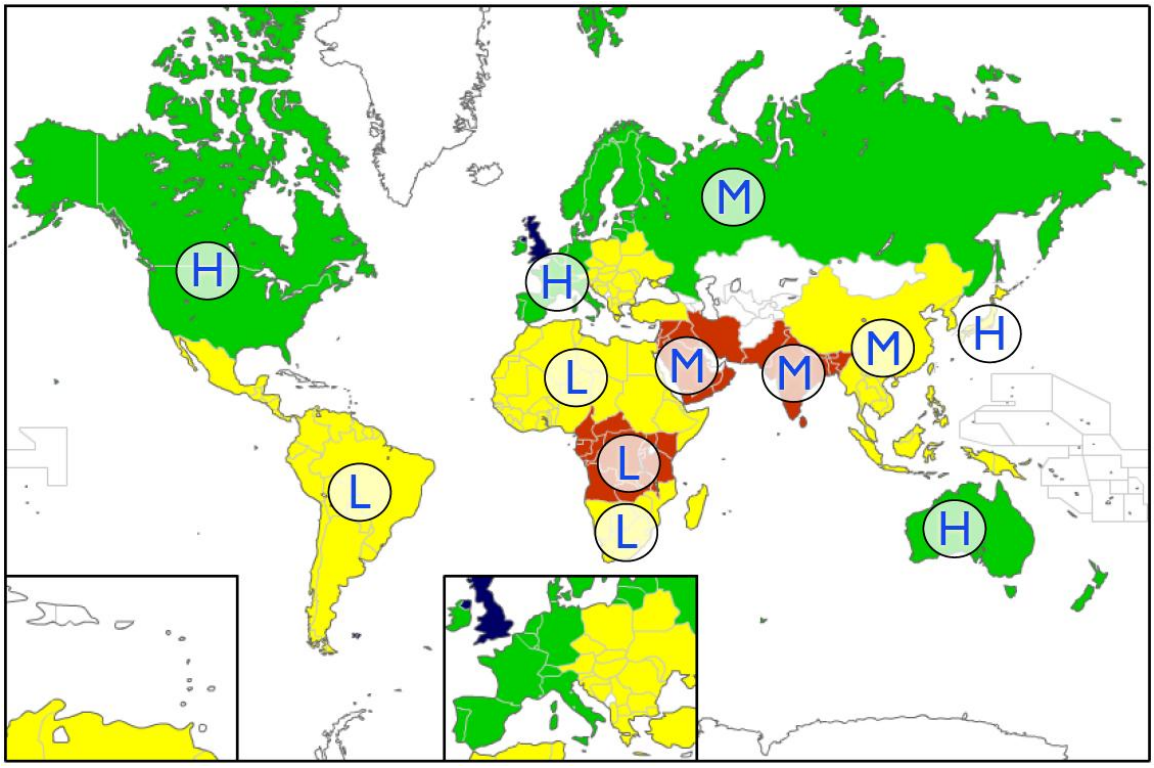
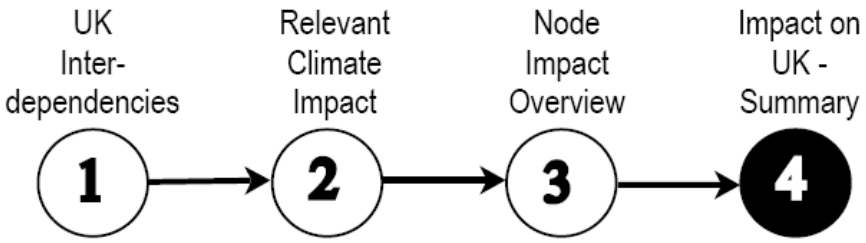


Figure 4.6.7 – Map showing the approximate degree of the UK financial services and investments to climate impact in different parts of the world. The H refers to high exposure, M to medium exposure and L to lower exposure.

It is important to note that the capacity for money flows, comparative money values and financial structures to change quickly introduces a high degree of uncertainty to these assessments. Also the development of the world

economy, including the arrival of Brazil, Russia, India and China to developed status and power will change these assessments.

4.6.4 Impact on UK Economy and Wealth - Summary



Recent studies (Coutts *et al* 2010*)* by Cambridge University show that "to secure a non-deteriorating trade account with unchanged levels of competitiveness the UK has to grow less quickly than its trading partners. Should it grow more quickly, there would be a tendency for the balance of payments to deteriorate. Coutts *et al* believe "*the boom in oil and the boom in finance may well have disguised this underlying structural problem* " (Coutts *et al*, 2010). This analysis again brings out one of the main insights of this report: climate change impact is a risk multiplier on the back a number of other distinct factors affecting economy and wealth.

The UK in particular "*has to undergo a large structural adjustment as the oil runs out; we are rightly concerned that the banking sector may not fill the gap; we know that the UK appears to suffer from a disparity in trade elasticities – with the import elasticity higher that the export elasticity – and we also know that there are asymmetric adjustment pressures. Capital market pressures placed on deficit countries to adjust can be much greater than the pressure applied to surplus countries. This means the costs of being over-concerned about the UK's balance of payments position may well be less than the costs of being under-concerned*" (Coutts *et al*, 2010).

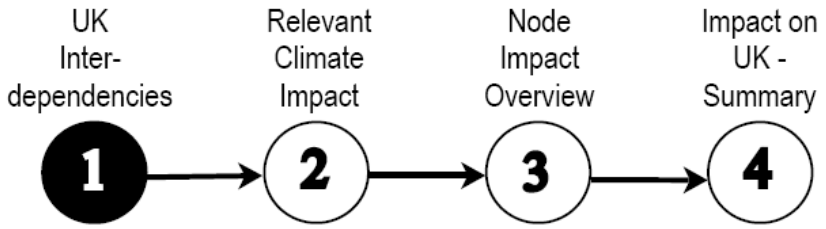
Despite the fact that climate change is a different form of driver, aspects of the impact of climate change as a form of contagion within the financial system are similar: availability of capital and an ability to do business are key to all subsectors. In this aspect, climate change drivers are not distinct from other

shocks and trends that financial systems accommodate, and like others, they have the potential to generate feedbacks to further undermine its stability (Silver *et al* 2010).

4.5 Governance and Institutions Dependencies

Focus Question: how far is the UK's response to climate change impacts elsewhere dependent on the response global governance institutions?

4.7.1 UK Interdependencies



Climate change impact elsewhere in the world will certainly have repercussions for policymaking and governance in the UK and internationally. The impact of the international dimension of climate change on UK governance, however, is also an area where there are unlikely to be simple one-to-one direct impacts of impacts. The secondary impacts tend to be of the type category 1 as defined in the introduction to section 4, in that they are mediated through a set of global institutions. This mediation operates in two ways; it can affect the degree of influence that the UK can exert on the rest of the world and it can also weaken that influence, which could lead to a category 2 impact. Multiple catastrophic consequences of climate change elsewhere could lead to major impacts on governance.

According to a recent review of risk, resilience and international security, "*we are in a period of crisis and opportunity for globalization. Over the past twenty years, the nature of the most significant threats to international security, stability, and prosperity has evolved rapidly. Global systems are now tightly interconnected, with the result that risk can and does spread freely across borders. Without effective mechanisms for responding to these changes, the world's capacity to prevent and manage crisis will be inadequate. In the worst case, we may find that the most severe shocks become sufficiently disruptive to threaten the integrity of the international system as a whole*" (Evans *et al.*, 2010).

The secondary climate impact risk for the UK is in the area of the robustness and evolutionary capacity of the set of global institutions that attempt to monitor, regulate and activate responses to challenges with world wide implications. These are mainly in the areas of security and economy, but, as we have seen through the 2009 Copenhagen meetings, the unavoidable global nature of climate change poses a new type of long term challenge to these institutions which they have not yet found adequate ways of response. Indeed there is significant body of opinion that current institutional policies and strategies are seriously out of line with what is needed. (Hartwell 2010)

The Hartwell study suggests: "… *the experience of the recent failure of the frontal assault on climate policy – the implausibly straight driveway from the present to a magically decarbonised future – suggests that a more indirect yet encompassing approach via the attainment of different objectives which bring contingent benefits is, indeed, the only one that is likely to be materially (in contrast to rhetorically) successful. As 'How to get climate policy back on course' already documented, despite being the dominant policy for many years, there is no evidence that, despite vast investment of time, effort and money, the "Kyoto" type approach has produced any discernable acceleration of decarbonisation whatsoever: not anywhere; not in any region*" (Hartwell, 2010).

The situation is complex and there are many interlinked drivers that create a generally "locked in" situation. One view of the situation is summarized in the systems map in Figure 4.7.1. The general picture is that of a declining spiral that is proving extremely difficult to unravel because the issues are not just about climate change but a whole range of geo-political issues across many nations of the world.

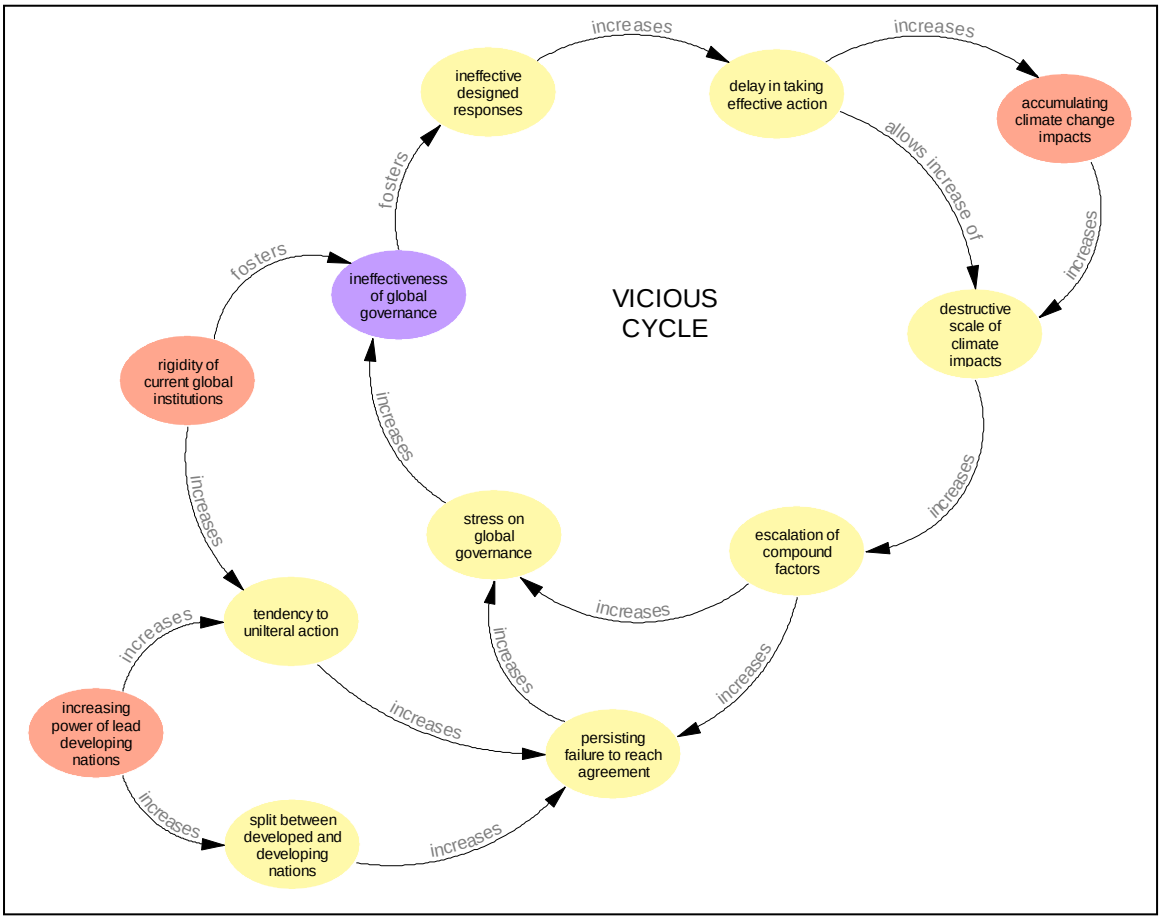


Fig 4.7.1 - Systems map of the tendency towards failure of international responses to dealing with climate change (based on verbal description by Depledge 2010)

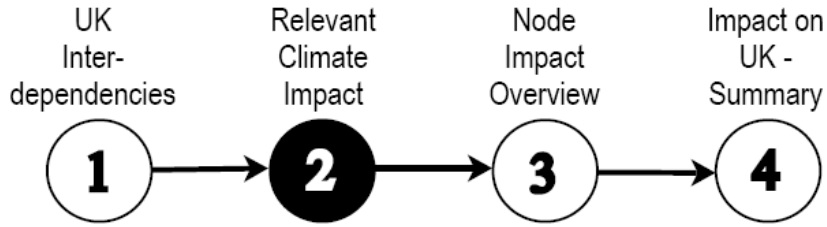
The following is a description of the key features of this systems diagram. The effectiveness of global governance is limited by the rigidity of the current global institutions and by the increasing stress they are placed under. The increasing power of the developing world increases the tendency to unilateral action and increasingly splits actions and policies of the developed and developing nations. This leads to persistent failure to reach agreement which generates stress on global governance. The lower the effectiveness of the global institutions, the less they are capable of designing effective responses thereby sustaining delay. In the delay period the climate change impacts

accumulate and so increase the scale of impacts world wide. The risk multiplication on the complex of global geo-political problems then further increases the stress on global governance. The global institutions are at risk of being caught in this vicious cycle where crisis makes things worse rather than better.

However there are also signs of new initiatives from newly emerging positions especially from the rapidly developing nations. The question then becomes to what extent can the vicious cycles be deconstructed and more effective dynamics put in their place. Some of the current trends are outlined below.

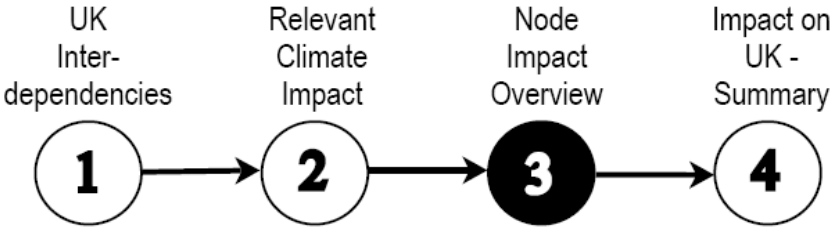
China has become more assertive about what it wants from multilateralism, and was a key player in the IMF financing and reform package agreed at the London Summit. **India** and **Brazil**, meanwhile, have demonstrated increased willingness and capacity to engage on global issues such as trade and counter-terrorism. All three countries were, with **South Africa**, instrumental to shaping the outcome of Copenhagen. Evans *et al* assess the situation as follows: "*The rise to global prominence of these emerging powers represents perhaps the most significant change to the context of global governance since the Second World War. The extent of their commitment to a rules-based global order will prove pivotal in the coming years, as will the nature of the actions they take to shape the international system to their advantage. So far, their increased engagement has complicated deal making in some areas, with their governments often lacking the capacity to make a full and consistent contribution across a crowded international agenda*" (Evans *et al*., 2010).

4.7.2 Relevant Climate Impact



The precise implications for the UK are likely to depend largely on the resilience of the global governance structures on which the UK depends. Because of its relatively weak position militarily and economically, the UK is increasingly reliant on structures such as the UN, EU and NATO to extend its influence abroad. For example, the former Foreign Secretary, David Miliband has argued that the EU magnifies UK influence around the world; others go further arguing that the UK is 'fundamentally dependent' on the EU if it is to have any impact on the direction of global governance. Consequently, the recent decline in EU influence, as demonstrated in Copenhagen, has contributed to a similar decline in the UK's influence over global affairs (Depledge 2010).

4.7.3 Governance and Institutions Overview



The UK is heavily dependent on global governance structures. The more immediate dependency is on the European Union (EU) itself, the United Nations (UN) and the North Atlantic Treaty Organisation (NATO). Also important but less closely linked are the International Monetary Fund (IMF), the World Bank (WB) and the World Trade organisation (WTO). This situation is represented in the diagram in Figure 4.7.2. Rather than a geographical map this shows the main transnational institutions that occupy the governance space.

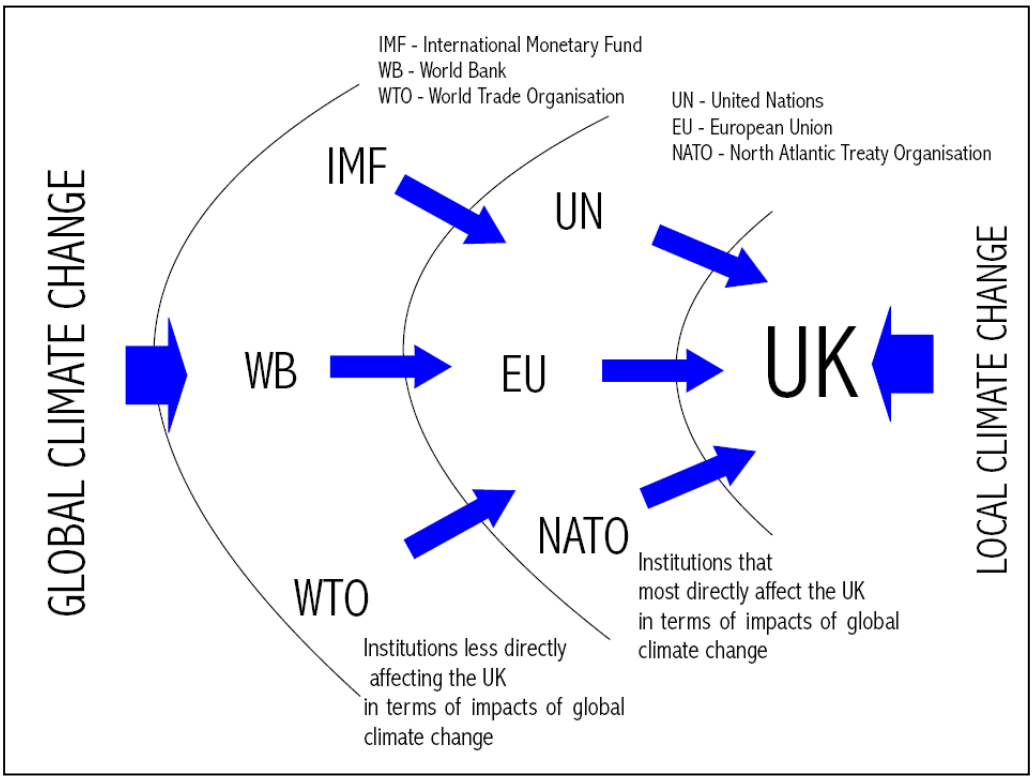
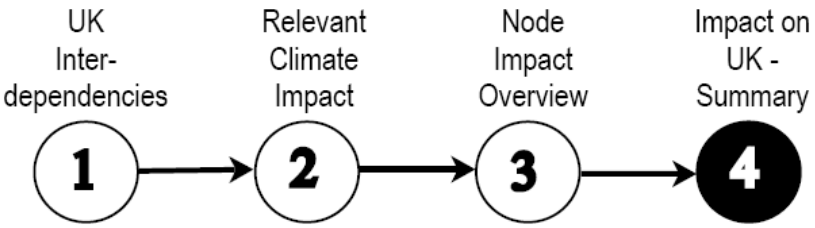


Fig 4.7.2 – Climate change impacts around the world impact on the UK governance structure mediated through the international governance structure.

If the integrity and mediation of these institutions is strong and relevant to all parties, and the UK sustains its influence in them, then the impacts on the UK are likely to be turned to its advantage. However, if international coherences collapse and we enter a world of multiple bilateral arrangements then the weakening position of the UK could well leave it marginalised and unable to mitigate repercussions of climate change impacts elsewhere.

4.7.4 Impact on UK Governance and Institutions - Summary



The main challenge to the UK is how far it still has the power and influence to shape global institutions to match the new levels of threat and disruption that could be multiplied by climate change impact around the world.

Concurrently, a growing 'operational gap' means that international institutions are struggling to adapt their operations to address climate change which by its nature cannot be managed or contained within international borders. Depledge expects "*that without reform and renewed purpose, the effectiveness of global governance structures as security actors will continue to decrease as global temperatures increase, as divisions are exacerbated and geopolitical positions become entrenched*" (Depledge 2010).

The opportunities to establish well-functioning global governance architecture will narrow as global temperatures rise, revealing a vicious circle: climate change can only be combated effectively through international cooperation, but with advancing climate change, the basis for constructive multilateralism will diminish. Climate change thus poses a challenge to international security, but classic, military-based security policy will be unable to make any major contributions to resolving the impending climate crises. (WGBU 2008)

Wallace summarises the situation as follows. "Given its potential to cause a serious decline in the liveability of different regions around the world, policymakers and others are beginning to identify climate change as a security threat. Although there is no consensus that this drives violent conflict, security concerns arise from its indirect impacts on local institutions in areas challenged by environmental degradation" (Wallace 2009).

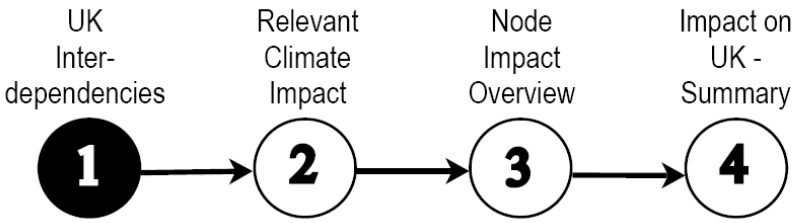
Institutions evolve or are created in response to the challenges they face. Climate change could become a globally uniting issue that may even – as the impacts accumulate – transcend fundamentalism and historic rivalry. Faced with the civilizational challenge to curb concentrations of CO_2 and equivalents in the atmosphere to a level of 350ppm in order to avoid long-term deterioration of the planetary life-support system (which is the most recent suggestion of the IPCC and below the current levels of 387ppm) humanity will have to collaborate at a global scale in unprecedented ways. Implementation of both mitigation and adaptive action will first and foremost have to be local and regional – everywhere - and therefore require a renewed commitment to governance structures that allow for subsidiarity.

Resilience, adaptability, and sustainability are all issues that require attention to appropriate scale, to the ways these scales interact, and to the need for maintaining diversity. They also require increased decentralization and redundancies in the system. Governance institutions will have to reflect this scale-linked sensitivity between local, regional, national, and international responsiveness and responsibility, into a framework for cooperation. There is a lot of rhetoric about the challenges and opportunities of climate change, while the scientific fact is that the global challenges will by far outweigh the regionalized opportunities. Nevertheless, the significant opportunity posed by this first truly global issue - one that can only be effectively met by humanity as a whole - is that we are challenged to evolve new institutions and ways of governance, that will inspire active citizens to implement a local and regional transition towards a global culture of sustainability.

4.8 Health

Focus Question: what might the implications of climate impacts elsewhere be for UK public health?

4.8.1 UK Interdependencies



There are different ways that the impact of climate change elsewhere ein the world might have repercussions for the UK. The various vectors of exchange, such as international transport, tourism and trade can be carriers for diseases. This already happens as we have seen from varieties of flu that have emerged the country. The implication of climate change is elsewhere is that it may increase the virulence of potentially imported diseases and it may release infectious organisms through, for example, temperature and humidity rise.

As well as the source country or region there is the factor of local climate change in the UK. For example, warmer conditions may enable organisms to thrive in the UK which are at the moment unsuited to the current environment. This analysis pays particular attention to the likely changing patterns of correlation between ecologies in different regions and changes in the UK which could significantly change disease vectors.

The major threats arising from the impact of climate change will be "*through changing patterns of disease, water and food insecurity, vulnerable shelter and human settlements, extreme climatic events, and population growth and migration. Although vector-borne diseases will expand their reach and death tolls, especially among elderly people, will increase because of heatwaves, the indirect effects of climate change on water, food security, and extreme*

climatic events are likely to have the biggest effect on global health" (Costello 2009).

The map in Figure 4.8.1 shows the typical regional effects of climate change on the health of those populations. The specific kinds of impacts that affect disability adjusted life years (DALY) and other measures of health are shown in Figure 4.8.2. Note that mitigation and adaptation can also carry health risks as well as climate impact itself.

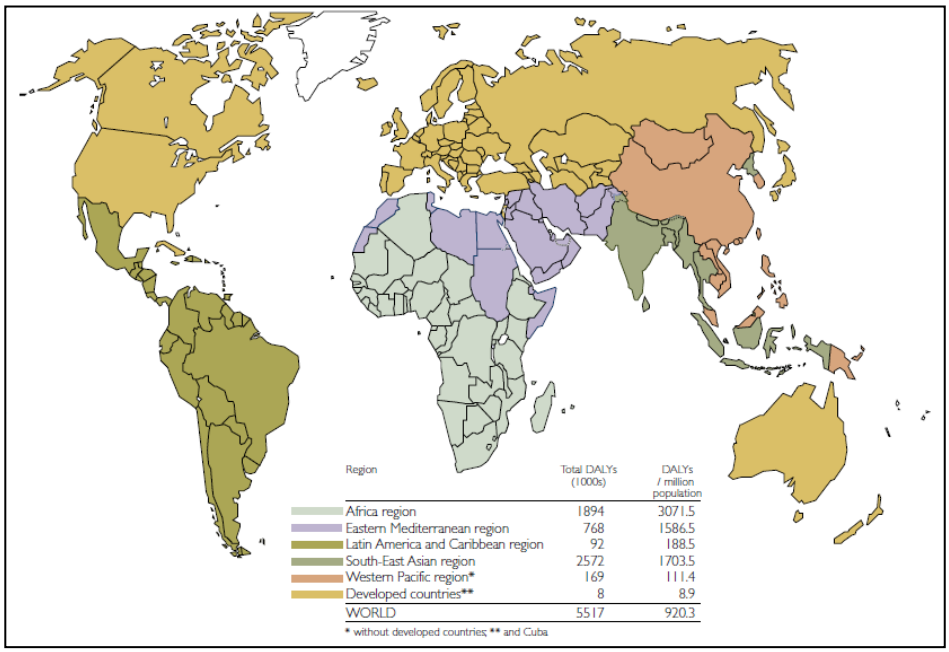
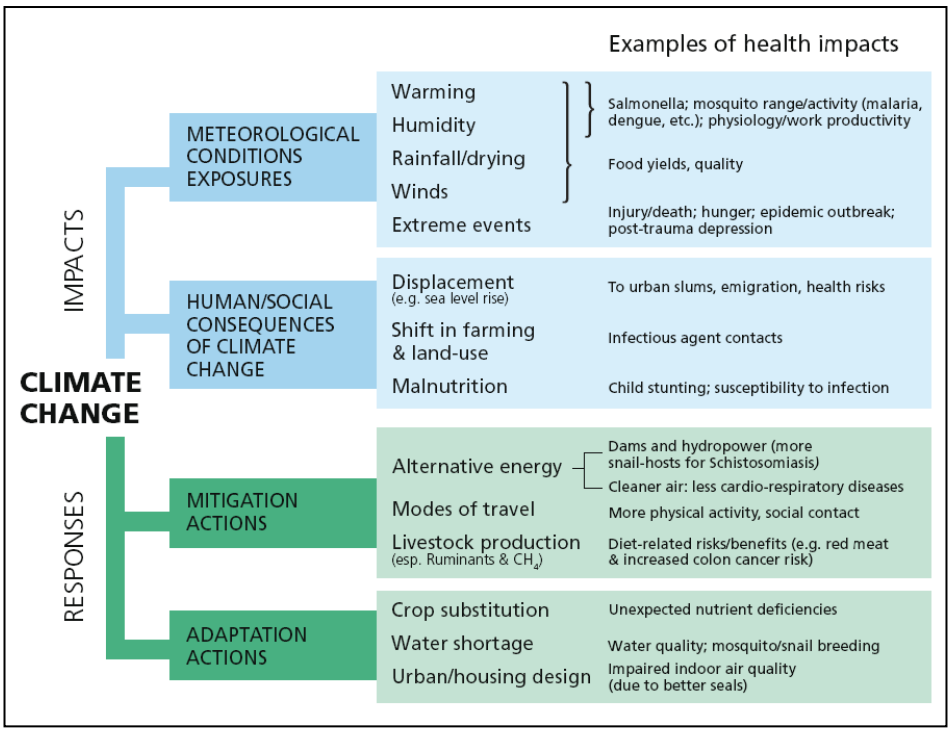


Figure 4.8.1 - Estimated effects of climate change in 2000, by WHO region. DALY = disability adjusted life year. The disability adjusted life year is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death.



`*Figure 4.8.2 - Effects of Climate Change on Human Health and Wellbeing (McMichael and Bertollini, 2009)*

Societies are highly vulnerable to even modest climate change, with poor nations and communities especially at risk. Temperature rises above 2°C will be challenging for contemporary societies to cope with and will increase the level of climate disruption through the rest of the century (Costello 2009).

For example, temperature affects the rate of pathogen maturation and replication within mosquitoes. Temperature rise tends to increase the density of insects in a particular area and the likelihood of infection. Therefore, some populations who have little or no immunity to new infections might be at increased risk. Vector reproduction, parasite development cycle, and bite frequency generally rise with temperature; therefore, malaria, tick-borne encephalitis, and dengue fever will become increasingly widespread (Costello 2009).

Changing patterns in the spread and frequency of illness and disease as have been predicted for gradual and extreme forms of climate change will have sociopolitical consequences. All epidemiological problems associated with

modernity, mobility and resource consumption will be exacerbated by climate-related social instabilities. As people migrate away from areas deteriorated by gradual warming or destroyed by extreme weather events, they not only place substantial demands on the ecosystems and social infrastructures into which they migrate, but also carry illnesses that emerge from shifts in infectious-disease vectors (Costello 2009).

Although it is clear that greater incidence of infectious diseases brought about elsewhere by climate change could increase the chances of vector infection into UK society, there is not sufficient research to make predictions. "*Infectious diseases, especially those transmitted via insect vectors or water, are sensitive to climatic conditions. Disease incidence data is needed to provide a baseline for epidemiological studies. The lack of precise knowledge of current disease incidence rates makes it difficult to comment about whether incidence is changing as a result of climatic conditions*" (McMichael 2003). There is insufficient data to gain any sense of scale of impact. This depends on a complex of factors including the vector of transmission, the suitability of the UK host environment, and the virulence of the pathogen.

However, on the basis of anticipated climate changes inferences can be made as to the areas to be aware of in considering what new diseases may occur as the climate warms. At present, on the basis of co-varying mean temperature, precipitation and vapour pressure, similar climatic conditions to those found in various parts of the UK are found extensively in Northern Europe, Asia west of the Caspian Sea, Japan, Eastern China and New Zealand.

Climate change has already had measurable effects on the varied climates of Europe. Further changes, such as overall warmer temperatures combined with more extreme temperatures at both ends of the scale, increased rainfall in Northern Europe, increased water scarcity in Southern Europe and even more extreme weather events, such as flooding and acute precipitation events across much of Northern and Central Europe, are anticipated. The transmission patterns of communicable diseases are influenced by many

factors, including climatic and ecological elements. It is widely anticipated that climate change will impact the spread of communicable diseases in Europe. In some instances these impacts will be favourable, but in many cases they will pose new threats to public health. Food- and water-borne disease incidences, for example, have been correlated to warmer temperatures. Disease vectors (e.g., mosquitoes, sandflies and ticks) are highly sensitive to climatic conditions, including temperature and humidity. The distribution of these vectors is expected to shift in Europe, particularly at their latitudinal and altitudinal limits, meaning that certain vector-borne diseases may be introduced to regions that have not previously encountered them (Lindgren and Ebi, 2010).

The changed climate in the UK is predicted to match the present climate in different parts of the world. Farther into the future for UK climates, the regions of similarity with present-day Europe then decrease; by the 2080s the climate predicted for much of Southern, Central and North-West England does not match any found in Europe today. If climate really is a determining factor for the arrival of new diseases into the UK, this exercise highlights the regions of the world from which we might expect to import problems. With data on which diseases occur in these places at the present time, we should be able to make more informed guesses as to the future risks of exotic diseases to inhabitants of the UK (Kovats Ed 2008). These are shown in the map Figure 4.8.3.

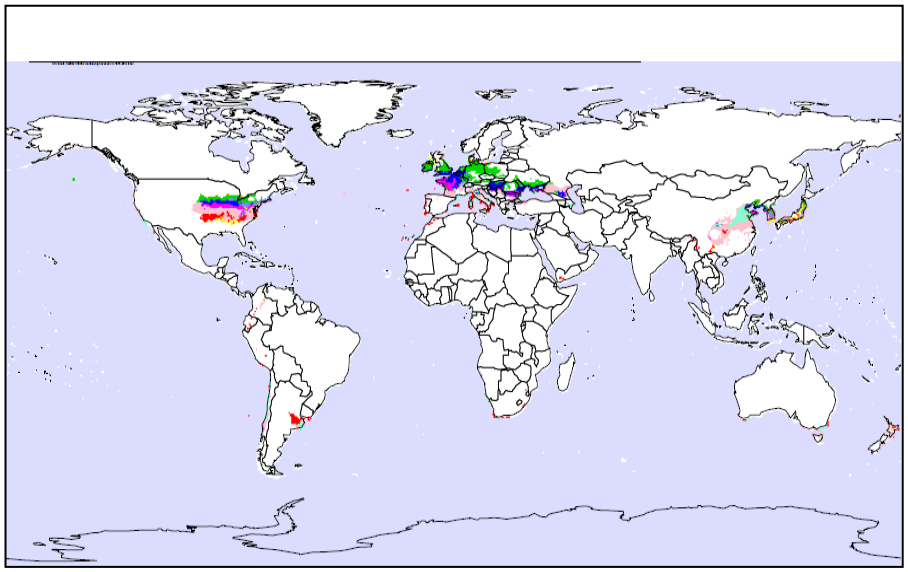


Fig 4.8.3 - Matching of 10 climatic zones based *on the UK climate HadCM2 2050s high scenario indicating possible sources of new pathogens. The UK might be prone to diseases that are prevalent in the indicated zones which will have a similar future climate to that predicted for the UK.(Kovats Ed 2008)*

The areas in Fig 4.8.3 can be related to the countries and regions covered in the preceding analysis of climate impact as shown in Figure 4.8.4.

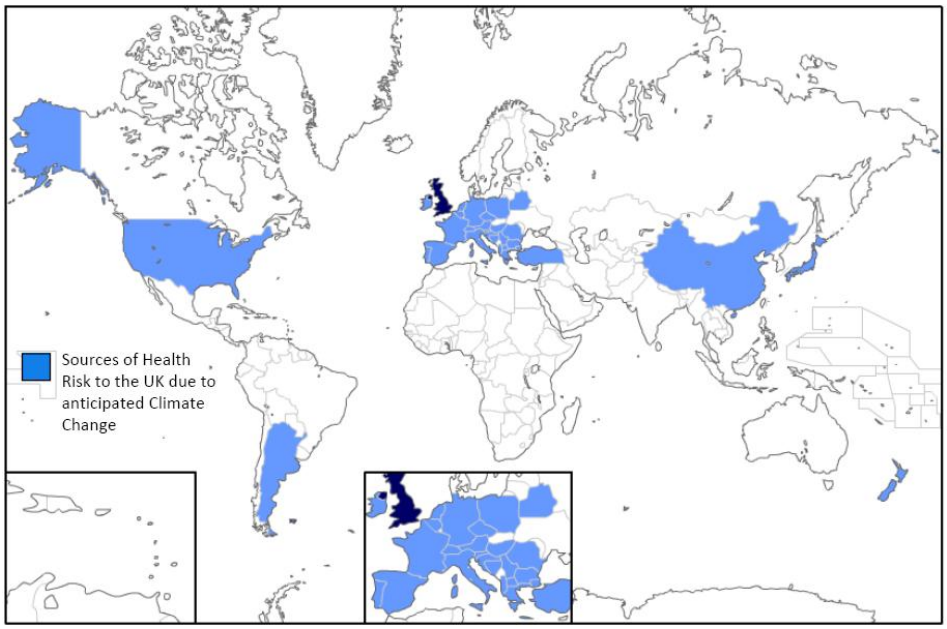
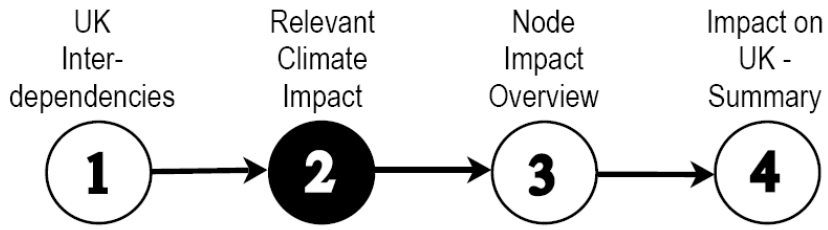


Figure 4.8.4 - Map of the main possible sources of health risks to the UK resulting from disease vectors released by climate change

4.8.2 Relevant Climate Impact



There follows a note on each of the main countries and regions highlighted in the map Fig 4.8.4. The points made about each country reported below are extracted from the World Stories in Book 2 Section 1 which supplies the context for their specific relevance.

Western Europe

- The estimated increases in heat-related mortality are projected to be lower than the estimated decrease in cold-related mortality.
- Food- and vector-borne diseases can also pose a danger through indirect effects of climate change altering the seasonal patterns of diseases
- The risk of local malaria transmission could spread in northern Europe

Central and Eastern Europe

- Like most other effects of climate change, those on health are unevenly distributed across Europe, with Central and Eastern Europe likely to experience the highest rise in heat-related deaths.
- In Eastern European countries per-capita health expenditure is relatively low, health services are less efficient in detecting and treating malaria cases, and the environmental measures to control mosquito distribution are often poorly implemented. This could eventually contribute to the uncontrolled spread of the disease in these countries.
- The following flood-related illnesses are already present in Central and Eastern Europe and are likely to increase with the effects of climate change: dysentery, typhoid, west Nile fever, cholera, hepatitis A and salmonella.

China

- Temperature increases and a higher incidence of heatwaves will result in increased illness and death. This could be highest in cities where temperatures are exacerbated by the urban heat island effect, particularly affecting vulnerable groups such as the poor, elderly and labourers.
- Occurrences of diarrhoeal and other bacterial diseases are very likely to increase as temperatures rise and water quality issues increase. Malaria, dengue fever, tick-borne encephalitis and many other vector-borne and infectious diseases are also likely to change in geographical range and frequency.

United States

- Communities across the United States are at-risk for negative health effects associated with climate change.
- Some positive health outcomes, notably reduced cold-weather mortality, are possible.
- It is possible that the population at risk from heat events will increase.
- A number of important pathogens commonly transmitted by food, water or animals are susceptible to changes in replication, survival, persistence, habitat range and transmission as a result of changing climatic conditions such as increasing temperature, precipitation and extreme weather events.
- The warmer temperatures associated with climate change are predicted to decrease dissolved oxygen levels, increase contaminant load to water bodies, reduce stream and river flows, foster algal blooms and increase the likelihood of saltwater intrusion near coastal regions thus impacting on human health.

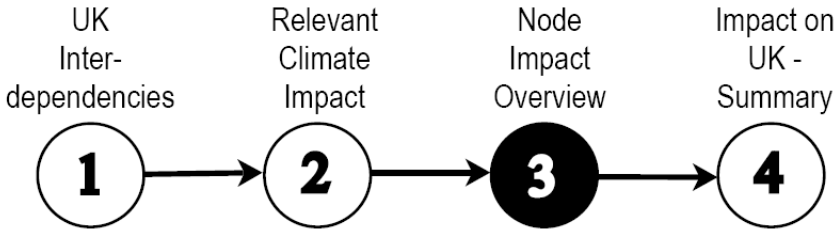
Andean S America

No specific health related information, but similar trends as discussed for other regions are likely to exist.

New Zealand

No specific health related information.

4.8.3 Health and Wellbeing Overview



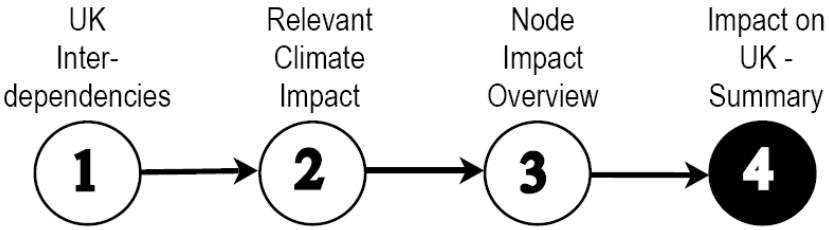
The World Health Organisation (McMichael 2003) estimates that the warming and precipitation trends due to anthropogenic climate change of the past 30 years already claim 150,000 lives annually. Many prevalent human diseases are linked to climate fluctuations, from cardiovascular mortality and respiratory illnesses due to heatwaves, to altered transmission of infectious diseases and malnutrition from crop failures. Uncertainty remains in attributing the expansion or resurgence of diseases to climate change, owing to lack of long-term, high-quality data sets as well as the large influence of socio-economic factors and changes in immunity and drug resistance. Here we review the growing evidence that climate–health relationships pose increasing health risks under future projections of climate change and that the warming trend over recent decades has already contributed to increased morbidity and mortality in many regions of the world.

Potentially vulnerable regions include the temperate latitudes which are projected to warm disproportionately, the regions around the Pacific and Indian oceans that are currently subjected to large rainfall variability due to the El Niño/Southern Oscillation and the margins of sprawling cities where the urban heat island effect could intensify extreme climatic events (Patz et al 2005).

The map in Figure 4.8.5 relates the exposure to climate vulnerability already assessed. The zones are marked with a question mark because there were insufficient data to make any kind of proportional estimation of high, medium or low.

Figure 4.8.5 - Based on the above analysis, the arrows on the map indicate the broad regions from which, as the climate changes, the UK may increasingly be susceptible to pathogens characteristic of those regions, and which are not currently present in the UK. The colours indicate the climate impact vulnerability of those areas.

4.8.4 Impact on UK Health and Wellbeing - Summary



Application of these models to current disease burdens suggests that, if the understanding of broad relationships between climate and disease is realistic, then climate change is already affecting human health. The total current estimated burden is small relative to other major risk factors measured under the same framework. However, in contrast to many other risk factors, climate change and its associated risks are increasing rather than decreasing over time (WHO 2003).

The interaction between climate change and disease epidemics is having an impact on both developing and industrialized countries. However, this impact is disproportionate. "*As developing countries continue to struggle with climate variability, the increased frequency of this variability leaves them with less and less time to recover, leading to a gradual and steady erosion of already reduced adaptive capacities. Interaction between global warming and ease of transportation between continents has facilitated the spread of vector borne diseases. No country is safe from invasion by pathogens …"* (Tsai and Liu, 2005). This is also the case for the UK which has extensive exchange of people and organic materials with the rest of the world.

Where in the world those risks will increase is most likely to come from the poorer regions that are also subject to greater climate vulnerability. They will "be at greatest health risk from climate change because of their lack of access to material and information resources and because of their typically lower average levels of health and resilience (nutritional and otherwise)." (McMichael 2003).

If the statement below is equally applicable to the UK then there is a case for paying much more attention to the health implications for the UK of climate impact elsewhere. "*The evidence suggests that the breadth of biologic responses to changes in climate is being underestimated. Treating climate-related ills will require preparation. Early-warning systems forecasting extreme weather can help to reduce casualties and curtail the spread of disease*" (Epstein 2005).

5 Conclusions

The challenge posed to this report's authors at the outset was to identify risks to the UK that become increasingly evident in considering the impact of climate change overseas, risks not identified by assessments focusing only on the direct impact of climate change at home. An approach based on systems mapping was considered appropriate since what is at issue in this inquiry is clearly the place of the UK within an interconnected and complex global system.

In order to produce the analysis in this report the authors have had to develop methods in two critical areas:

- assessing global vulnerability to climate change at regional scales;
- understanding the UK's critical dependencies in a global system.

5.1 Assessing Global Vulnerability to Climate Change

The first requirement in order to address the policy challenge was to integrate the synthesis literature on the impact of climate change in all the parts of the world that are likely to have implications for the UK. Many reports of research concentrate on a specific focus area; for example temperature, disease, agriculture, sea level and so on. There are relatively few that consider the impact of climate change on specific geographies in the round. The method needed to view climate impact in the round.

Little work appears to have been done on a systematic appreciation of climate impact across many dimensions that take into account the *systemic nature of climate impact* in itself on social ecological system (SES). Although it is clear that direct impacts of climate change on specific aspects of and SES will interact with each other to generate an overall pattern of impact there is little in the literature that takes an holistic approach. To appreciate of each country

or region as a social ecological system (SES) rather than just an area on a global map the World System Model (see Section 1 p.4) developed by Anthony Hodgson in collaboration with the International Futures Forum (IFF) was used as a framework.. This provides an heuristic device to facilitate rapid comparison of countries and regions as complex, interconnected systems. Like any heuristic device of value, it also reveals that there are gaps in the information which may indicate further fruitful areas for investigation.

A systems perspective requires not only consideration of impact of climate change but also the capacity of these country and regional social ecological systems to absorb or cope with the impacts identified; in other words their adaptive capacity. To gain some appreciation of adaptive capacity – again on a basis that will allow some cross-comparison across countries and regions – a set of well established proxies has been used. Selecting an appropriate set of proxies to calculate adaptive capacity has enabled production of a *global map of vulnerability to climate change,(see Section 2 Fig 2.8)* taking into account differential capacity to absorb climate impact in different parts of the world.

5.2 Understanding the UK's Critical Dependencies

Well structured information about the UK's critical dependencies on, and hence vulnerabilities to, the global system is scarce and scattered. The UK itself is a complex system and its dependencies and critical interconnections into the rest of the global system (of which it is a part) need to be considered holistically. The World System Model was used as a framework for making sense of largely sector-based studies of critical dependencies produced by expert groups working in parallel with the systems mapping project.

The impact on the UK of climate change impact elsewhere is mediated in three ways, as described in the introduction to Section 4. The categories in summary are:

Category 1 Impact – a dependence or relationship is disturbed by the impact of climate change on another region/country mediated through a functioning global market and commodity speculation.

Category 2 Impact – the degree of impact is sufficient to provoke alternative ways of satisfying that need. This type of impact requires an increase in adaptive capacity leading to a change of pattern. If left to market mechanisms alone, there will be a high risk of the market failing to ameliorate the impact.

Category 3 Impact – the impact of climate change elsewhere creates a major and probably irreversible dislocation. At this level there is local catastrophe. This scale of event will be beyond the ameliorating effect of market mechanisms, beyond the current adaptive capacity and will lead to or require drastic measures such as rationing and other legislatory interventions.

The primary potential impacts on the UK identified in eight areas are summarised below. These are drawn from the more detailed account in Section 4. A headline summary also appears in Figure 5.1.

Health

Climate change is modifying and will continue to modify the pathogens to which the UK is exposed and vulnerable. The critical factor is the possible changes in the UK climate that might make it vulnerable to diseases that have not previously been congruent with the UK climate as well as the release elsewhere of pathogens previously unknown in the UK.

Food

The food security of the UK is most tightly coupled with Western Europe such that climate impact on food production in, say, the Mediterranean area could have strong repercussions. The dependency on Africa is important but less critical. However, it is probably more prone to climate disruption at the source. The USA provides a smaller but significant component of UK food imports. Food may also become more subject to political control as a result of climate change elsewhere.

Trade

The flow of trade between the UK and the rest of the world could be strongly affected by climate impact elsewhere, especially in China and Eastern Europe. These disruption would be particularly in ports and transportation featuring highly in UK exports and imports. However, unless the disruptions are massive and abrupt, most of these effects will be absorbed by the appropriate markets. Clearly this will lead to price rises for imports and some market disruption for exports. More serious would be circumstances in which cumulative and synchronous effects trigger market failure or more disruptive outcomes like resource wars.

Energy

The UK depends on energy imports at a level which could render it vulnerable to restrictions on availability of oil and also the cut-off of gas supplies. Although smaller and slower changes will be absorbed by the market and pricing, there is the possibility of physical supply disruptions that cannot be compensated by the market mechanism. Factors triggering such challenges are likely to be geo-political in nature with climate issues a secondary background.

Water

In a country with plentiful water supplies (except SE England), water as such is not of particular concern. However, there are many imports, especially food, which contain large quantities of embedded or virtual water which has its source in the place of origin, for example through irrigation. As such areas become themselves more water stressed, so there is a risk that UK imports will suffer restrictions. In this respect there could be merit in considering how the UK's overseas 'water footprint' could be reduced.

Infrastructure

In a highly interconnected world the UK is very dependent on the efficient and reliable functioning of global trade infrastructure. This is especially so since a large portion of manufactured goods originate elsewhere, especially SE Asia

and China. Climate change events have the potential to disrupt supply chains upon which the UK depends. Some key routes and ports are in locations which are high on the climate impact and vulnerability scale.

Wealth

The UK's position as a major global financial centre with assets distributed around the world gives this sector a high exposure. Climate change impact in some other regions is a risk multiplier that can be a threat to banking, insurance and assets. Significant climate impact can rapidly change values, risks and knock-on effects across the financial system. These factors as risk multipliers to the UK could undermine stability, or provide additional disruptive shocks to the already fragile stability of the global financial system in which the UK is a major player.

Governance

The politics and the realities of climate change elsewhere have and will continue to have a strong impact on governance. However, this is unlikely to be a simple direct effect. Such impacts are generally mediated through a whole range of international institutions. This means that the power of the UK to respond to changes and shocks is limited by the influence it can or cannot exert in these various institutions. The challenge is further exacerbate by the deficiencies in existing international institutions (even more so than by their absence) in dealing with local crises that have global repercussions. The situation is complex and interlinked factors create a locked-in vicious spiral which it is hard to change.

Further to this analysis of the World System nodes, there is a 2nd order level of consideration for the UK which relates to possible synchronous impacts in more than one of the above eight areas and interaction between them. The stronger the broad impact of climate change across the world, the more likely this is to be a strategic factor.

Figure 5.1 indicates the potential of such synchronous impact. Review of simultaneous impact from all areas provides a challenging picture for UK adaptive planning to consider.

Viewing the UK itself as a system shows that a basic list of potential risks and impacts falls short of representing the real complexity of the multi-layered situation. Firstly there is a need to make the distinction between potential impact of climate change in any given region and the real level of vulnerability to that impact, taking into account adaptive capacity. Secondly, there is a set of intermediate effects to be considered between impact elsewhere and consequential impact on the UK. This is an intervening layer of interaction beyond the UK, including potential mitigation and adaptation strategies in other countries and regions participating in the global system. Thirdly there are the modifications in impact afforded by global systems that will mitigate impact or spread its effects - like the market and institutions of governance.

This work also reveals the critical reliance the UK places on the international mechanism of efficient, open global markets to secure resources on which it depends when sources of supply fall foul of climate-related vulnerabilities.

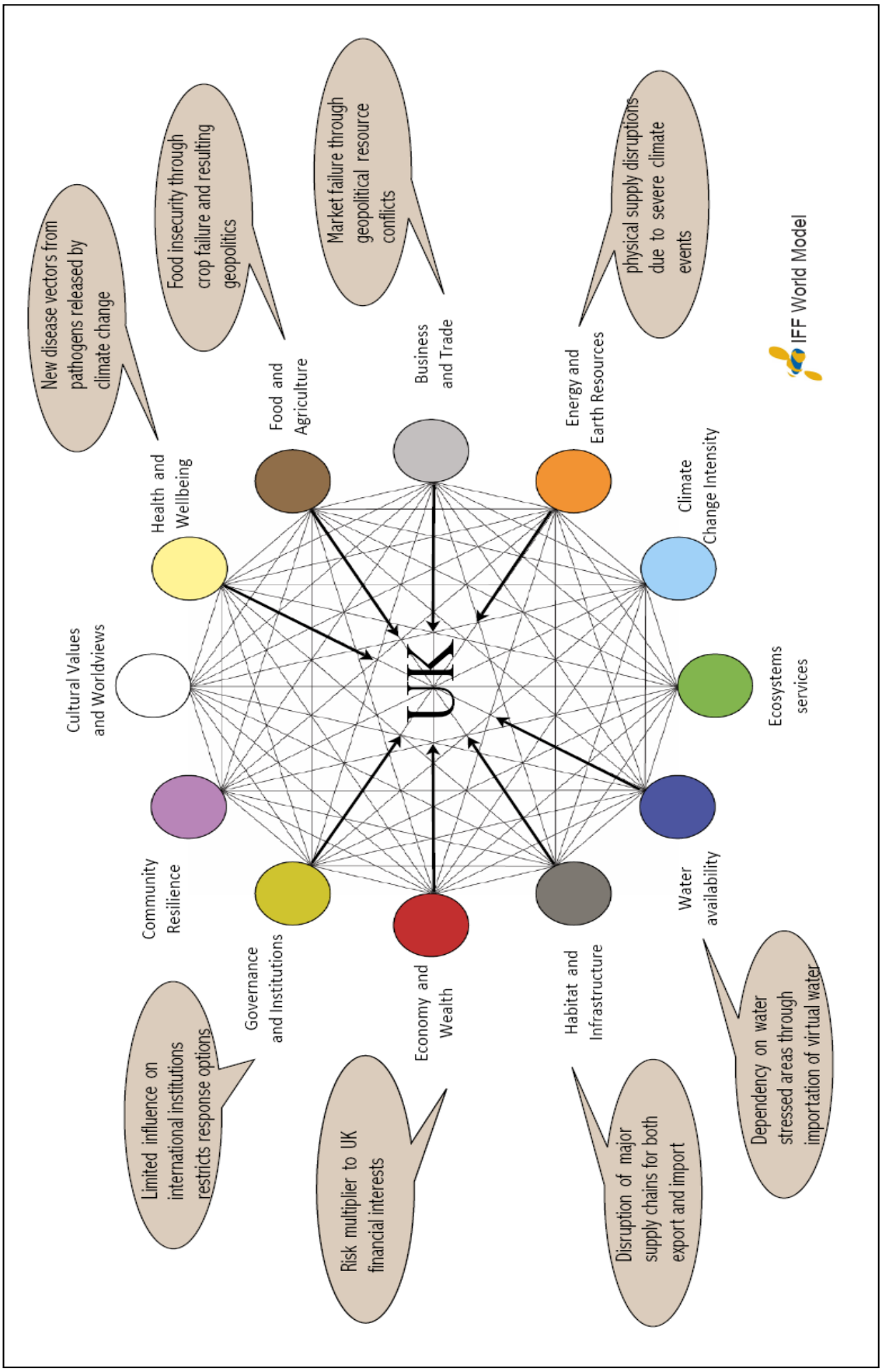


Figure 5.1 - Summary of some possible major impacts on the UK of climate change impact elsewhere indicating the potential for synchronous failure.

Hence the three over-riding conclusions for policy arising from this aspect of the study are:

1. improve understanding of the UK's critical systemic dependencies, their priority and interdependence.
2. assess the vulnerability of critical elements of the UK system to climate change impact overseas to gain a better strategic understanding of the risks inherent in climate change to specific, identified, critical dependencies.
3. place risks to the capacity and effectiveness of supra-national governance mechanisms and of supra-national markets on the UK critical risk assessment register in relation to climate change.

5.3 From Trends to Foresight, Prediction to Anticipation, Risk to Resilience

This is the view that our traditional policy processes are reaching the limit of their effectiveness in taking on a challenge of this level of complexity and uncertainty. The scope of the project – global, with a focus on the UK, spanning data across numerous disciplines and a timescale running out to 2100 – is a difficult exercise blending evidence based review with a futures orientation. It inevitably steps over the bounds of peer-reviewed, evidence-based analytical weighing of options.

The systems-based mapping approach provides a tool and framework to make some headway. But there remains an inherent dilemma in endeavouring to make systems maps of the potential impact of climate change. On the one hand, such mapping needs to be based on the best and most reliable evidence and scientific reasoning available. However, systems science points out that emergent unforeseeable properties are in the nature of complex systems. This forecasting the future on the basis of past trends cannot be a reliable method except in certain limited areas. The system maps in this report should be regarded as a combination of rapid synthesis and

point of departure for more through studies, whether of synthesis of scientific evidence or the creation of 'hard to imagine' scenarios (See Book 2 Section 3).

Systems mapping, in the face of this complexity, has two main contributions. Firstly, it provides a tool for gathering diverse information into an holistic representation for rapid assimilation and enquiry.. Secondly, it provides a platform for anticipating what might happen in the future on the basis that the underlying structure of things is often the determinant of future behaviour, rather than just historical trends (Hodgson 2007).

The value to the policy maker and decision maker relates to the process of informing and shaping policy options in a way that take account of what is known, what is unknown and what can be anticipated as possible.

Aside from the substantive conclusions and implications for policy outlined elsewhere in this report, the success of the methodology itself suggests some promising avenues for more effective policy making in this area in the future:

1. Adopt the IFF World System Model (or a variant) as a common, government-wide framework for scanning and data synthesis. Interviews conducted across Whitehall at the start of the study identified this as a significant missing support for effective policy making. As one official put it:
"*We need a better handle on what knowledge already exists. We don't know what we know. There are links to eg Hadley Centre, RUSI, Chatham House. Other governments are doing good work – eg France, US, Australia. But there is no joined-up, thorough way of seeing a full set of evidence. We need a framework for logging information, and for more regular sharing and knowledge management across government*".

This work has shown that the model is robust for this purpose.

2. Share this report with other international partners in the hope that they too can start to log and share research and scanning information on a similar

system mapping basis. This will provide a common platform for international communication and for increasing the effectiveness of early warning of critical climate impacts. The map of global vulnerabilities is a common resource, useful in all geographies and capable of being extended and refined.

3. Where there are perceived weaknesses in the research data or in the proxy measures used, improve them. The method is set out transparently at all stages in order that it can be adopted and adapted to take into account new research or more detailed analysis.

Finally, the report points to a further critical shift in policy thinking – from risk management to resilience. When it is possible to isolate individual events with a fair degree of precision a risk-by-risk management approach is appropriate. When an uncertainty is viewed as a 'risk' it is implicitly assigned a quantitative measure of predictability – which can then be managed and prioritised accordingly.

However, what this report identifies is that in the area of climate change climate impact there are now too many parallel and interconnected sources of system failure to be handled in this way, and that the level of uncertainty based on critical interconnections between them is so 'unpredictable' that the language of risk itself may now be unsuited to the task. There are numerous challenges to the system that can and must be anticipated but cannot be predicted. (Homer-Dixon 2006)

Hence it is important to consider the overall resilience of the UK social ecological system (SES), and seek a lowering of its levels of vulnerability to climate change and consequent risks. The World System Model provides a good initial framework for appreciating the overall resilience of the UK as a system – and has been effectively used for that purpose already at city level. (Hodgson, in press 2011)

The shift to resilience is of a piece with thinking in other areas, including new approaches to national security (e.g. Ramo 2009). The new mantra for risk

management in a surprisingly interconnected world is ‘plan for anything, but don’t plan for everything’. The authors of this report have come to the same conclusion in relation to the impact of the impacts of climate change on the UK. The traditional approach of critical risk identification, prioritisation and management will a) be expensive and b) be vulnerable to a critical concatenation of events that the risk management approach fails to anticipate. The authors hope that this report provides the building blocks for a more intelligent and more effective approach.

Section 6 - References

Note: While it was necessary for the analysis in this report to include block-quotes from other literature sources, these often include references to other analysis. It was not considered relevant within the scope of this report to analyse the content of these "implicit" references. However, as such, the authors cannot verify the content or analysis of these implicit references, and as such readers should refer to the original material for more information. They are listed here under the synthesis reference within which they occur. They are indicated by stars to differentiate them from primary material analysed for this report.

Acclimatise, (2010) *Building Business Resilience to Inevitable Climate Change* – A Carbon Disclosure Project Report, Global Mining, Oxford.

Ackoff, R. L. (1999) *Re-creating the Corporation,* New York: Oxford University Press,

Adelphi, (2009) *Regional Security Implications of Climate Change: A Synopsis,* Adelphi Consult & Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany.

★ Martens 2007

★ Middleton 2008

Adger, Brooks, Bentham, Agnew and Eriksen (2004) *New indicators of vulnerability and adaptive capacity*, Tyndall Centre for Climate Change Research, Technical Report 7, January 2004.

AFP, (2007) *Climate Change and Africa,* 8th Meeting of the African Partnership Forum, Berlin, Germany, 22-23 May 2007. <http://www.africapartnershipforum.org/dataoecd/57/7/38897900.pdf> [Accessed 8th September 2010].

Agrawala, S. et al, (2003) *Development and Climate Change in Bangladesh: Focus on* Coastal *Flooding and the Sundarbans,* Organisation for Economic Co-operation and Development, <www.oecd.org/dataoecd/46/55/21055658.pdf > [Accessed 9th September 2010].

Alcamo, J. et al, (2007) *Europe. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.,eds.,Cambridge University Press, Cambridge, UK, pp.541-580.

Ambler-Edwards, S. et al, (2009) *Food Futures: Rethinking UK Strategy*, Chatham House Report, London: Royal Institute of International Affairs (Chatham House).

American Society and Council of the Americas (AS & COA.) (2009) *Energy and Climate Change in Brazil,* <www.as-coa.org> [Accessed 8th September 2010].

Atlas du Monde Diplomatique(2006) Armand Colin, *Panorama des ports de commerce mondiaux 2003,* ISEMAR January 2005. Images Economique du Monde 2002, Sedes.

Australian Department of Climate Change, (2010) *Australia's Fifth National Communication on Climate Change, A report under the United Nations Convention Framework on Climate Change,* Australian Department of Climate Change, Commonwealth of Australia.

Bates, B.C. *et al.* eds, (2008) *Climate Change and Water*, Technical Paper of the Intergovernmental Panel of Climate Change, IPCC Secretariat, Geneva.

★ Arnell, 2004
★ Arnell, 2006a
★ Chappell and Agnew, 2004
★ Cury and Shannon, 2004
★ Dai et al., 2004a
★ ECF and Potsdam Institute, 2004
★ Gonzalez, 2001
★ Kang et al., 2001
★ Kosek et al., 2003
★ Mendelsohn et al., 2000a, b
★ Nchito et al., 1998
★ Nicholson et al., 2000
★ Riebsame et al, 1995
★ Salewicz, 1995
★ Seo and Mendelsohn, 2006
★ Stige et al, 2006
★ UNEP/GRID-Arendal, 2002
★ Vörösmarty et al, 2005
★ Warren et al., 2006
★ WHO/UNICEF, 2000
★ World Water Forum, 2000

Behrens, A. et al, (2010) *Future Impacts on Climate Change Across Europe,* Centre for European Policy Studies (CEPS), Brussels.

★ European Commission, 2009a
★ IPCC, 2007b
★ MICE, 2005
★ Schröter et al., 2005 in IPCC, 2007b

Bigio, A. G. (2009) Adapting *to Climate Change and Preparing for Natural Disasters in the Coastal Cities of North Africa,* The World Bank.

Boko et al, (2007) *Africa: Climate Change 2007 – Impacts, Adaptation and Vulnerability,* Contributions of Working Group II to the Forth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp.433-467.

Brocklehurst, J. et al, (2010) *Office for National Statistics: United Kingdom Balance of Payments - The Pink Book,* Basingstoke, Hampshire: Palgrave Macmillan.

Brown, N., (2008) *Climate Change in the UK Overseas Territories,* Joint Nature Conservation Committee

★ Mimura *et al*., 2007
★ Parry *et al*., 2007

Brown, O. & Crawford, A. (2009) *Climate Change and Security in Africa: A Study for the Nordic-African Foreign Ministers Meeting,* International Institute for Sustainable Development (IISD), Winnipeg, Manitoba, Canada.

★ Boko et al., 2007
★ Campbell et al, 2007
★ ECOSOC, 2008
★ ISDR, 2004
★ Nyong and Fiki, 2005
★ Smith and Vivekananda, 2007
★ UNDP, 2007
★ UNFPA, 2008
★ UN-HABITAT, 2008
★ WBGU, 2007

Brown, O. & Crawford, A. (2009) *Rising Temperatures, Rising Tensions: Climate change and the risk of violent conflict in the Middle East,* International Institute for Sustainable Development (IISD), Winnipeg, Manitoba, Canada.

Bueno R. et al, (2008) *The Caribbean and Climate Change: The Cost of Inaction,* Stockholm Environment Institute – US Center, <http://www.sei-us.org/climate-and-energy/Caribbean_Inaction_Cost.htm> [Accessed 8th September 2010].

California Energy Commission (2005) *California's Water-Energy Relationship,* Klien.

California Natural Resources Agency, 2009, *Climate Adaptation Strategy*, Discussion Draft - A Report to the Governor of the State of California

Canada. National Round Table on the Environment and the Economy. (2009). *True North: Adapting Infrastructure to Climate Change in Northern Canada*. Ottawa: NRTEE,

Canadian Institute for Climate Studies (CICS), (2001) *The Impact of Climate Change on a Climate Severity Index,* Canadian Institute for Climate Studies CICS, Victoria.

Canoura, C. (2009) *Latin America and the Irreversible Effects of a Warmer Planet,* First Regional Report on Climate Change, TierraAmerica Environment and Development, sponsored by UNDP, UNEP, and the World Bank, <www.tierramerica.net> [Accessed 8th September 2010].

Caribbean Catastrophe Risk Insurance Facility (CCRIF), (2009) *Briefing Document: Climate Change and the Caribbean Economies: Implications, Adaptation and Risk* Management*, http://www.preventionweb.net/english/professional/publications/v.php?id=11472 [Accessed 13th September 2010]*

Cassman, KG (2007) *Climate change, biofuels, and global food security* - Environmental Research Letters, **2** 2007 - iopscience.iop.org

CEPS (2010) *The Impact of Climate Change Across Europe* 2010, Centre for European Policy Studies

★ Aaheim et al, 2008
★ AEA, 2007
★ CLAVIER, 2009
★ Ciscar et al., 2009
★ Eskeland et al, 2008
★ European Commission, 2009

★ Mechler et al, 2009
★ Stuzczynksi et al, 2000
Chapagain, A. and Orr, S. (2008) *UK Water Footprint: the impact of the UK's food supply and fibre consumption on global water resources*, Volume 1, WWF - UK.
Chattopadhyay, N. (2008) *Climate Change and Food Security in India,* Presentation at International Symposium on Climate Change and Food Security in South Asia, Dhaka, Bangladesh, 2008. <http://www.wamis.org/agm/meetings/rsama08/S402-Chattopadhyay-Climate-change_Food-Security.pdf> [Accessed 8th September 2010].
CIFOR (2008) *Adaptation to Climate Change in Africa: Synergies with biodiversity and* forest*,* Nkem, J., Idinoba, M., Brockhaus, M., Kalame, F., Tas, A; Centre for International Forestry Research & Stockholm Environment Institute.
Ciscar, J.C ed, (2009) *Climate change impacts in Europe: Final Report on PESETA Research Project,* European Commission.
★ Mather *et al.*, 2005
★ Scott *et al.*, 2008
CNA Corporation (2007) *National Security and the Threat of Climate Change,* The CNA Corporation, Alexandria, Virginia.
CNCCP (2007) *China's National Climate Change Programme,* National Development and Reform Commission, People's Republic of China. <http://en.ndrc.gov.cn/newsrelease/P020070604561191006823.pdf> [Accessed 8th September 2010].
Contreras-Lisperguer, R. & de Cuba, L. (2008) *The Potential Impact of Climate Change on the Energy Sector in the Caribbean Region – An effort to understand how climate change may impact the productivity of existing and future energy production systems in* the *Caribbean,* Department of Sustainable Development, Organization of American States.
★ de Cuba, et. al, 2008
★ IPCC 2001
Cornejo, P. (2007) *Ecuador Case Study: Climate Change Impacts on Fisheries,* United Nations Development Programme (UNDP), Human Development Report 2007/2008, occasional paper, 2007, pp.48.
Costello, A. et al. (2009), *Managing the Health Effects of Climate Change*, The Lancet*,* 373(9676), pp.1693-1733.
Coutts, K., Rowthorn, R. and Martin, B. (2010), *Prospects for the UK Balance of Payments,* Civitas: Institute for the Study of Civil Society.
Cruz, R.V. et al, (2007), *Asia - Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*,* Parry, M.L. et al, eds. Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK, pp. 469-506.
CSIRO (2005) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions,* Preston, B.L. and Jones, R.N. http://www.csiro.au/files/files/p6fy.pdf [Accessed 22nd February 2011].
Curry, A. and Hodgson, A. (2008), *Seeing in Multiple Horizons – Connecting Futures to Strategy*, Journal of Futures Studies Volume 13 Number 1

DEFRA, (2006) *Food Security and the UK: An evidence and Analysis Paper,* http://www.defra.gov.uk/evidence/economics/foodfarm/reports/documents/foodsecurity.pdf [Accessed 13th September 2010]

DEFRA, (2007) *Overview of the benefits and carbon costs of the African horticultural trade with the UK*, Food Chain Economics Unit, Department for Environment Food and Rural Affairs

DEFRA, (2009) *Agriculture in the United Kingdom 2009,* Department for Environment Food and Rural Affairs

★Dell et al, 2008

Department for International Development (DFID), (2009) *A Latin American Perspective on Climate Change,* Latin America Partner Programme Arrangement (LAPPA), Department for International Development, UK Aid.

Department of Environmental Affairs and Tourism (DEAT), (2004) *A National Climate* Change *Response Strategy for South Africa, Department* of Environmental Affairs and Tourism, Pretoria. <http://unfccc.int/files/meetings/seminar/application/pdf/sem_sup3_south_africa.pdf> [Accessed 8th September 2010].

Department of Environmental Affairs and Tourism (DEAT), (2006) *South Africa Environment Outlook: A Report on the State of the Environment – Key Executive Findings*, Department of Environmental Affairs and Tourism, Pretoria.

Department of Environmental Affairs and Tourism (DEAT), (2009) *Effects of Climate Change,* Department of Environmental Affairs and Tourism, Republic of South Africa http://soer.deat.gov.za/themes.aspx?m=174#3558 [Accessed 13th September 2010]

Depledge, D., & Feakin, T. (2010), *Understanding the Implications of Climate Change for Global Governance and Institutions,* http://bis.gov.uk/foresight.

Ditlevsen, P. D., and S. J. Johnsen, (2010) *Tipping points: Early warning and wishful thinking*, Geophys. Res. Lett., DOI: 10.1029/2010GL044486

Dorff, R.H.(2008), *Good Governance and Stability*, in Global Climate Change: National Security Implications, Strategic Studies Institute, Carlisle, Pennsylvania.

E3G, (2009) *Systematic Risk Management Approaches to Climate Change: London Workshop,* http://www.e3g.org/programmes/climate-articles/systematic-risk-management-approaches-to-climate-change-london-workshop/ [Accessed 28th August 2010]

Easterling, W. *et al***, (**2004) *Coping with Global Climate Change,* Pew Center on Global Climate Change, Arlington, VA.

Energy Information Administration (EIA), Clough, L. ed. (2008) *Energy profile of the United States,* In: Encyclopedia of Earth, Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment), [First published in the Encyclopedia of Earth February 24, 2007; Last revised April 14, 2008] <http://www.eoearth.org/article/Energy_profile_of_the_United_States> [Accessed 8th September 2010].

Energy Information Administration (EIA), (2009) *International Energy Outlook 2009*, Office of Integrated Analysis and Forecasting, US Department of Energy. Washington D.C. <www.eia.doe.gov/oiaf/ieo/index.html> [Accessed 8th September 2010].

Epstein, P. (2005) *Climate Change and Human Health*, The New England Journal of Medicine*,* 353(14), pp.1433-1436.

European Environment Agency (EEA) (2004) *Impacts of Europe's changing climate,* Office for Official Publications of the European Communities (OPOCE).

European Environment Agency (EEA) (2007) *Europe's Environment: The Fourth Assessment,* Office for Official Publications of the European Communities (OPOCE).

European Environment Agency (EEA) (2010), *10 Messages for 2010 - Agricultural Ecosystems,* European Environment Agency (EEA), Copenhagen.

★ Jones‐Walters and Nieto, 2007

Evans, A., Jones, B. and Stephen, D. (2010) *Confronting the long crisis of globalization - Risk, resilience and international order*, Washington DC: Brookings Institution, and New York: Centre for International Co-operation.

Fay, M. et al, (2009) *Adapting to Climate Change in Europe and Central Asia,* International Bank for Reconstruction and Development, The World Bank.

Fitzharris, K.B. et al, (2007) *Australia and New Zealand, Climate Change 2007: Impacts, Adaptation and Vulnerability,* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Parry, M.L. et al. eds. Cambridge University Press, Cambridge, UK, pp.507-540.

FAO (2008) *Climate Change, Water, and Food Security, A Technical Background Paper,* Food and Agriculture Organization of the United Nations, <http://www.fao.org/nr/water/docs/HLC08-FAOWater-E.pdf> [Accessed 8th September 2010].

FAO (2008) *Ecosystems Services Sustain Agricultural Productivity and Resilience*, in Feeding the World Fact Sheet, http://www.fao.org/nr/gen/gen_080502_en.htm [Accessed 13th September 2010]

FAO (2010) *Ecosystem Services Sustain Agricultural Productivity and Resilience,* Fact Sheet, <http://www.un.org/esa/sustdev/csd/csd16/documents/fao_factsheet/ecosystem.pdf> [Accessed 9th September 2010].

Foreign Policy, (2010) *Failed State Index,* http://www.foreignpolicy.com/articles/2010/06/21/2010_failed_states_index_interactive_map_and_rankings, [Accessed 28th August 2010]

Friends of the Earth Middle East (FOEME), (2007) *Climate Change: A New Threat to Middle East Security*, Prepared for the UN CC Conference, Bali Indonesia, International Task Force on Preventive Diplomacy & East West Institute, <www.foeme.org> [Accessed 9th September 2010].

Froggatt, A. and Lahn, G. (2010) *Lloyd's 360° Risk Insight, Sustainable energy security: strategic risks and opportunities for business,* Chatham House Report, London: Royal Institute of International Affairs (Chatham House).

Garnaut. (2008) *Garnaut Climate Change Review – Interim Report to the Commonwealth, State and Territory Governments of Australia,* Garnaut Climate Change Review.

Giorgi,F. (2008) *Uncertainties in Regional Climate Change Projections,* http://www.bridgingthegap.si/pdf/Adapation to climate change/Filippo Giorgi UNCERTAINTIES IN REGIONAL CLIMATE CHANGE PROJECTIONS.pdf [Accessed 6th October 2010]

Global Climate Change Impacts in the United States, (2009) Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press

Goosen, H. Bessembinder, J. and Stuyt, L. (2009) *Climate Impact Atlas promotes the use of climate information in policy making,* The Netherlands National Climate Research, <www.climateresearchnetherlands.nl> [Accessed 8th September 2010]

Government of Brazil, (2008) *National Plan on Climate Change: Executive Summary,* Interministerial Committee on Climate Change, Brasilia, Decree No. 6263.

Graaff, M. & Joubert, L. (2009) *South Africa's farmers respond to climate change threat,* Green Futures, Forum for the Future. <http://www.forumforthefuture.org.uk/greenfutures/articles/South_Africas_farmers_respond_to_climate_change_threat> [Accessed on 9th September 2010].

Gregory, P. J. et al, (2005) *Climate Change and Food Security*, Philosophical Transactions of the Royal Society B, 360, p. 2143.

Hadley Centre (2010) NCEAS (shipping routes 1), FAO (ports2), GIS-Lab (pipelines3), NOAA (night-time lights)

Hanson, C. et al. (2008) *The Corporate Ecosystems Services Review,* World Resource Institute, Meridian Institute, and World Business Council for Sustainable Development, <http://www.wri.org/publication/corporate-ecosystem-services-review> [Accessed 9th September 2010].

Hastings, A. (2010) *Regime shifts in ecological systems can occur with no warning*, Ecology Letters, http://www.universityofcalifornia.edu/news/article/22806 [Accessed 13 September 2010]

Heylighen,F. and Joslyn, C. (2001) *The Law of Requisite Variety,* Principia Cybernetica*,* http://pespmc1.vub.ac.be/reqvar.html

HM Treasury *(2010)* http://archive.treasury.gov.uk/pub/html/top/top8/rec.html [Accessed on August, 16th, 2010:]

Hodgson, A.M. *Deepening Scenarios with System Structure,* in Sharpe and van der Heijden (eds) *Scenarios for Success – Turning Insights into Action,* John Wiley & Sons

Hodgson, A. M., (in press 2011) *World Visioning – Towards a Platform for Planetary learning,* Triarchy

Hoekstra, A.M. (2009) *Human appropriation of natural capital: A comparison of ecological footprint and water footprint analysis*, Ecological Economics 68(7): pp.1963-1974.

Hoekstra, A.Y. and Chapagain, A.K. (2007) *Water footprints of nations: water use by people as a function of their consumption pattern*, Water Resources Management 21(1): pp.35-48.

Homer-Dixon, T. (2006) *The Upside of Down,* Souvenir Press

Horn, R.E. (2011), http://www.stanford.edu/~rhorn/ [Accessed 28th February 2011]

Huang, Y. et al, (2009) *A primary assessment of climate change impact on rice production in China*, Climate Change: Global Risks, Challenges and Decisions, IOP Conf. Series: Earth and Environment Science 6, <http://www.iop.org/EJ/article/1755-1315/6/47/472003/ees9_6_472003.pdf?request-id=6000cc90-550f-47f9-a007-43b06535c4c7> [Accessed 9th September 2010].

IASC Task Force on Climate Change, (2009) *Climate Change, Food Insecurity and Hunger – Key Messages for the UNFCCC Negotiators,* Submitted by WFP, FAO, IFRC, Oxfam, CARE, CARITAS, WHO and Save the Children, <www.icva.ch/doc00003211.html> [Accessed 9th September 2010].

International Food Policy Research Institute (IFPRI) (2008) *Vulnerability and the Impact of Climate Change in South Africa's Limpopo River Basin*, Sharon Shewmake for the International Food Policy Research Institute. <http://www.ifpri.org/sites/default/files/publications/rb15_02.pdf> [Accessed 9th September 2010].

International Food Policy Research Institute (IFPRI) (2009) *Climate Change: Impact on Agriculture and Costs of Adaptation,* Fact sheet for Latin America and the Caribbean, International Food Policy Research Institute (IFPRI), Washington DC.

International Food Policy Research Institute (IFPRI), (2009) *Mapping the South African Farming Sector's Vulnerability to Climate Change and Variability,* International Food Policy Research Institute. <http://www.ifpri.org/sites/default/files/publications/rb15_03.pdf> [Accessed 9th September 2010].

International Fund for Agricultural Development (IFAD), (2008) *Making a difference in Asia and the Pacific,* <http://www.ifad.org/newsletter/pi/s_4.htm> [Accessed 9th September 2010].

IFF World System Model 2010, International Futures Forum, http://www.internationalfuturesforum.com/iff_world_model.php [Accessed 28th February 2011]

International Institute for Applied Systems Analysis (IASA), (2009) *Biofuels and Food Security – Implications of an accelerated biofuels production*, International Institute for Applied Systems Analysis, Vienna, Austria, <www.iiasa.ac.at> [Accessed 9th September 2010].

International Institute for Sustainable Development (IISD), (2003) *Vulnerability of North African Countries to Climatic Changes: Adaptation and Implementation Strategies for Climate Change*, International Institute for Sustainable Development (IISD), Winnipeg, Manitoba, Canada.

International Trade Centre (ITC), (2010) *Climate change and the coffee industry, technical paper*, International Trade Centre, Geneva, Switzerland, <www.thecoffeeguide.org > [Accessed 9th September 2010].

IPCC, 2007: *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution *of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp

★ Asner et al., 2005

★ Asseng et al., 2004
★ Atwell et al., 2003
★ Austin et al., 2000
★ Bunn and Arthington, 2002
★ CAE, 2005
★ Crimp et al., 2002
★ CSIRO, 2002
★ Dymond et al., 2006
★ Falconer, 1997
★ Fearnside, 2001
★ Gifford and Howden, 2001
★ Githeko and Woodward, 2003
★ ISDR, 2004
★ Ghannoum et al., 2000
★ Glade, 1998
★ Griffiths, 1990
★ Hall and Burns, 2002
★ Herron et al., 2002
★ Howden and Jones, 2004
★ Howden et al 1999d
★ Howden et al., 2001a
★ Hughes, 2003
★ Kenny et al., 2000
★ Kovats et al. 2005
★ Luo et al., 2003
★ Loukos et al., 2003
★ McMichael et al., 2003
★ MCDEM, 2004
★ MDBMC, 1999
★ MfE, 2001
★ PAHO, 2003
★ Peresand Lake, 2003
★ Poloczanska et al., 2007
★ Reyenga et al., 2001
★ Schallenberg et al., 2003
★ Sinclair et al., 2000
★ Simms, 2005
★ Stephens et al., 2007
★ Stokes and Ash, 2006
★ Sutherst et al., 2000
★ Thresher et al., 1989, 1992, 1994
★ Viney et al., 2003
★ Woods and Howard-Williams, 2004
Jensen, J.K., (2009) *Climate Change and Rural Communities in the US, Draft Briefing Paper,* Rural Policy Research Institute
★ Cliff, 2008
★ GAO, 2009
★ Johnson, 2009
★ National Oceanic and Atmospheric Administration, 2009

Johnston, M.H. et al, (2009) *Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation,* Canadian Council of Forest Ministers.

Jones, B. and Olken, B. (2010) *Temperature and Exports,* Vox – Research-based policy analysis and commentary from leading economists. <http://www.voxeu.org/index.php?q=node/4889> [Accessed 30th July 2010].

Kalin, R., (2008) *Is there 'water, water everywhere'?* Sustainability Matters, David Livingston Centre for Sustainability, University of Strathclyde
http://www.strath.ac.uk/media/departments/civilengineering/dlcs/newsletter/sustainability-matters-issue-4.pdf [Accessed 6th October 2010]

King, I., (2007) *Climate Change and the Caribbean: the case and the responses, Adapting to Climate Change in the Caribbean Project* (ACCC), http://www.un.org/esa/sustdev/natlinfo/indicators/idsd/workshops/workshop10-27-31/07_IDSD%20CC%20Adapt%20%20Activities.ppt [Accessed 6th October 2010]

Kireeva, A. (2009) *Russia government reviews doctrine on climate change, prompting cheers and jeers,* The Bellona Foundation, <http://www.bellona.org/articles/articles_2009/climate_doctrine> [Accessed 9th September 2010].

Kovats, S. ed, (2008) *Health Effects of Climate Change in the UK 2008,* Health Protection Agency (HPA).

Lindgren, E. and Ebi, K.L. (2010) *Climate change and communicable diseases in the EU Member States,* ECDC European Centre for Disease Prevention and Control, <www.ecdc.europa.eu/en/.../1003_TED_handbook_climatechange.pdf> [Accessed 8th September 2010].

Lorand, J. and Olson, K. (2008) *California Leaders Under Pressure – Sustainability and Complexity, 2008-2028,* http://greenyourmanagement.com/Site/Summit_Info_files/Fort%20Baker%20Summit%20Bro.pdf [Accessed 6th October 2010].

Mabey, N. (2009) *E3G Workshop: Risk Management of Climate Change,* <http://www.e3g.org/programmes/climate-articles/systematic-risk-management-approaches-to-climate-change-london-workshop/> [Accessed 28th August 2010].

Majra, J.P. & Gur, A. (2009) *Climate change and health: Why should India be concerned*? Indian Journal of Occupational and Environmental Medicine, 13(1) pp.11-16.

Margin, G. et al, (2007) *Latin America. Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Parry, M.L. et al. eds. Cambridge University Press, Cambridge, UK, pp. 581-615.

Mayers, J. et al, (2009) *Water Ecosystems services and poverty under climate change: Key Issues and research Priorities*, International Institute for Environment and Development (IIED) report for DFID. <http://www.iied.org/pubs/display.php?o=13549IIED> [Accessed 9th September 2010].

McMichael, A. et al, (2005) Millenium Ecosystem Assessment, In Norgaard, R. and Wilbanks, T. eds. *Linking Ecosystems Services and Human Well-being,* <http://www.millenniumassessment.org/documents/document.341.aspx.pdf> [Accessed 9th September].

McMichael, A. et al, (2003) *Climate change and human health: risks and responses, Summary,* World Health Organisation (WHO).

McMichael, A. et al, (2007) *Food, livestock production, energy, climate change, and health*, The Lancet, 370(9594) pp.1253-1263.

Mesarovic, M. and Pestel, E. (1975) *Mankind at the Turning Point: The second report to the Club of Rome.* E.P. Dutton & Co. New York.

Met Office (2008) *Impacts of Climate Change: Canada*,

★ Christensen et al., 2007
★ Field et al., 2007
★ Fleury et al, 2006
★ Trenberth et al, 2007

Met Office, (2008) *Impact of Climate Change South America*

★ Hales et al, 2002
★ Magrin et al, 2007
★ Pongsumpun et al., 2008

Met Office, (2008) Impacts of Climate Change – South Africa – Summary Document

★ Benhin, 2006
★ Boko et al, 2007
★ Christensen et al., 2007
★ Clark et al, 2003
★ Fleury et al, 2006
★ Simmons et al, 2004
★ South Africa Info, 2008
★ State of the Environment Report – South Africa, 2008

Met Office, (2008a) *Impacts of Climate Change – Poland*, October 2008, Prepared by Felicity Liggins, Climate Change Consultant, Met Office Hadley Centre

Met Office, (2008b) *Impacts of Climate Change – Czech Republic*,October 2008, Prepared by Felicity Liggins, Climate Change Consultant, Met Office Hadley Centre

★ Olesen et al., 2007

Met Office, (2009) Vulnerability of global energy infrastructure to climate change – Scoping Study, prepared by Met Office Hadley Centre, December 2009

★ Field et al, 2007
★ Meehl et al, 2007

Met Office, (2009) *Impacts of Climate Change: China*

★ Cruz et al., 2007
★ Hu et al, 2001)
★ Liu et al, 2001
★ Lin et al, 2004
★ Patz et al, 2007
★ Peng et al, 2004
★ Stern, 2007
★ Takahashi et al, 2007

★ Thomas, 2008

Met Office (2010) *Physical Resources and Commodities and Climate Change*, Lewis, K., Witham, C. & McCarthy, R. http://bis.gov.uk/foresight.

Midgley, G.F. et al. (2002) *Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot*, Global Ecology & Biogeography, 11, pp.445 – 451.

Millennium Ecosystem Assessment, (2005) *Ecosystems and Human Well-being: Desertification Synthesis*, World Resources Institute, Washington, DC.

Mimura, N. L. et al. (2007) *Small islands. Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L. et al. eds. Cambridge University Press, Cambridge, UK, pp.687-716.

Ministry of Defence, (2010) *Global Strategic Trends – Out To 2040,* Development, Concepts and Doctrine Centre (DCDC), Shrivenham, UK.

Morrison, J. et al, (2009) *Water Scarcity & Climate Change: Growing Risks for Businesses & Investors - A Ceres Report,* Pacific Institute, <www.ceres.org/Document.Doc?id=406> [Accessed 8th September 2010].

Muriel, P. et al. (2005) *Climate Change and Agriculture in the United Kingdom,* Department for Environment Food and Rural Affairs (DEFRA).

Narain, S. et al. (2009) *Climate Change Perspectives from India,* United Nations Development Programme (UNDP), India, <http://undp.org.in/?q=climate-change-perspectives-India> [Accessed 9th September 2010].

National Intelligence Council (NIC), (2008) *Global Trends 2025: A Transformed World,* US Government Printing Office. <www.dni.gov/nic/NIC_2025_project.html> [Accessed 9th September 2010].

National Intelligence Council (NIC), (2009) *China: The Impact of Climate Change to 2030 - A commissioned Research Report.* <http://www.dni.gov/nic/PDF_GIF_otherprod/climate_change/climate2030_china.pdf> [Accessed 9th September 2010].

National Intelligence Council (NIC), (2009) *India: The Impact of Climate Change to 2030 - Geopolitical Implications*, Prepared jointly by CENTRA Technology, Inc. and Scitor Corporation.

National Intelligence Council (NIC), (2009) *North Africa: The Impact of Climate Change to 2030 (Selected Countries) – A Commissioned Research Report*, <http://www.dni.gov/nic/special_climate2030.html> [Accessed 9th September 2010].

National Intelligence Council (NIC), (2009) *Russia: The Impact of Climate Change to 2030, A commissioned research Report,* Joint Global Change Research Institute and Battelle Memorial Institute, Pacific Northwest Division.

National Intelligence Council (NIC), (2009) *Southeast Asia and Pacific Islands: The Impact of Climate Change to 2030, A commissioned research Report,* Joint Global Change Research Institute and Battelle Memorial Institute, Pacific Northwest Division, Sictor Corporation.

National Intelligence Council (NIC), (2010) *Mexico, The Caribbean, and Central America: The Impact of Climate Change to 2030, A commissioned research Report,* Joint Global Change Research Institute and Battelle Memorial

Institute, Pacific Northwest Division.

National Round Table on the Environment and the Economy (NRTEE), (2009) *True North: Adapting Infrastructure to Climate Change in Northern Canada* <http://www.nrtee-trnee.com/eng/publications/true-north/chapter2-true-north-eng.php> [Accessed 8th September 2010].

Nelson, *et al,* (2009) *Climate Change: Impact on Agriculture and Cost of Adaptation,* International Food Policy Research Institute, Washington, D.C.

New Zealand Ministry of the Environment, (2004) *Climate Change Impacts on New Zealand,* Ministry of the Environment, Climate Change Group, Wellington, NZ. http://www.mfe.govt.nz/publications/climate/impacts-report/index.html [Accessed 1st March 2011]

Nicholls, R. J. et al, (2007) *Ranking Port Cities With High Exposure And Vulnerability To Climate Extremes: Exposure Estimates,* Paris, OECD, OECD Environment Working Papers No. 1 ENV/WKP, <www.oecd.org/dataoecd/16/58/39720578.pdf> [Accessed 4th August 2010].

Nicholls, R. & Kebede, A.S., (2010) *The Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100*, http://bis.gov.uk/foresight.

NIWA National Climate Centre, (2008) *Climate Change – Projections for New Zealand,* <www.niwascience.co.nz/ncc> [Accessed 9th September 2010].

Nkem, J., Idinoba, M., Brockhaus, M., Kalame, F. and Tas, A. (2008) *Adaptation to Climate Change in Africa: Synergies with biodiversity and forest,* Centre for International Forestry Research & Stockholm Environment Institute (CIFOR), Indonesia.

Novo, P., Casado, R., Garrido, A. and Varela-Ortega, C. (2009) *Virtual Water and Water Footprint: A Case Study from Spain,* Department of Agricultural Economics and Social Sciences, Technical University of Madrid, <http://www.fnca.eu/congresoiberico/documentos/c0313.pdf> [Accessed on 3rd August 2010].

Office for National Statistics (2010) *United Kingdom Balance of Payments – The Pink Book*

Orr, S., Cartwright, A. and Tickner, D. (2009) *Understanding Water Risks: A primer on the consequences of water scarcity for government and business,* WWF Water Security Series 4, <www.wwf.org.uk/wwf_articles.cfm?unewsid=2842> [Accessed 8th September 2010].

Ostry, A. et al, (2008) *Climate Change and Health in British Columbia,* Pacific Institute for Climate Solutions, University of Victoria, Victoria, B.C.

★ Moore et al., 2007
★ Mote and Hamlet, 2001
★ Patz et al, 1996
★ Rivera et al, 2004
★ Stewart et al, 2004
★ Wilkinson, 2008
★ Zebarth et al, 1997
★ Zhang et al, 2001

Oxfam, (2009) *Climate Change, Development and Energy Problems in South Africa: Another World is Possible, Executive Summary,* Sustainable Energy and Climate Change Partnership, Earthlife Africa. <http://www.oxfam.org/policy/climate-change-and-south-africa-another-world-possible> [Accessed 9th September 2010].

Pacific Institute (2009) *Online Update November 2009* http://www.pacinst.org/publications/online_update/nov_2009_online_update.html [Accessed 23rd February 2011]

Pai, N. (2008) *Climate Change and National Security: Preparing India for New Conflict Scenarios,* The Indian National Policy Brief. <http://nationalinterest.in/wp-content/uploads/2008/04/inipolicybrief-no1-climatechangeandnationalsecurity-nitinpai-april2008.pdf> [Accessed 9th September 2010]

Painter, J. (2007) *Deglaciation in the Andean Region,* United Nations Development Program (UNDP), Human Development Report 2007/2008, Occasional paper 2007/55,United Nations Development Programme, New York.

★ Frazer and Rojas, 2007

Parry, M.L. et al, (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, pp.541-580.

★ Benhin, 2006

★ Thornton et al, 2006

Patz, J., Campbell-Lendrum, D., Holloway, J. and Foley, T. (2005) *Impact of regional climate change on human health*, Nature*,* 418 pp.310-317.

Pearce, K. et al, eds. (2007) *Climate Change in Australia – Technical Report*, Commonwealth Scientific and Industrial Research Organisation, Australia.

Perelet, R. et al, (2008) *Climate Change. Russia Country Paper,* Human Development Report 2007/2008, Occasional Paper 2007/12, United Nations Development Programme, New York.

Preston, B.L. and Jones, R.N. (2005) *Climate Change Impacts on Australia and Benefits of Early Action to Reduce Global Greenhouse Gas Emissions,* Commonwealth Scientific and Industrial Research Organisation, Australia.

Prins, G. et al, (2010) *The Hartwell Paper: A New Direction for Climate Policy After the Crash of 2009*, May, <http://eprints.lse.ac.uk/27939/> [Accessed 8th September 2010).

Ranganathan, J. et al, (2008) *Ecosystems Services: A Guide for Decision Makers,* World Resource Institute, <http://www.wri.org/publication/ecosystem-services-a-guide-for-decision-makers> [Accessed 9th September 2010].

Rekacewicz, P. and Bournay, E. (2006) *Merchandise Ports and likely waste transit points, 2003,* <https://qed.princeton.edu/index.php/User:Student/Major_Merchandise_Ports_and_Likely_Waste_Transit_Points,_2003> [Accessed on 8th September 2010].

Revi, A. (2008) Climate change risk: an adaptation and mitigation agenda for Indian cities, *Environment & Urbanization,* 20(1), pp.207-229.

Revich, B. (2006) *Climate Change in Russia – possible consequences for health,* Institute of Agricultural Prognosis, Russian Academy of Sciences (RAN) <http://en.civilg8.ru/2239.php> [Accessed 9th September 2010].

Richardson, K. et al. (2009) *Synthesis Report: Climate Change Global Risks, Challenges & Decisions,* International Alliance of Research Universities, Avaliable at: <www.climatecongress.ku.dk> [Accessed 6th September 2010].

Rockström et al, (2009) Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society* 14(2), 32, <http://www.ecologyandsociety.org/vol14/iss2/art32/> [Accessed 9th September 2010].

Salzmann, N. et al, (2009) Integrated assessment and adaptation to climate change impacts in the Peruvian Andes, *Advances in Geoscience,* 22, pp.35-39.

Sathaye, et al, (2006) Climate change, sustainable development and India: Global and national concerns, *Current Science*, 90(3), pp.314-325.

Sawyer, D. (2008) Climate change, biofuels and eco-social impacts in the Brazilian Amazon and Cerrado, *Phil. Trans. R. Soc. B,* 2008, 363, pp.1747-1752.

Schindler, D. (2010) *Ecosystem Services and Biodiversity Issues in the Canadian Boreal Biome: The Cumulative Effects of Human Disturbance and a Changing Climate,* Inter Academy Panel Biodiversity Conference: Integrating ecosystem services into biodiversity management, The Royal Society, London.

Schubert, R. et al, (2008) *Climate Change as a Security Risk,* German Advisory Council on Global Change (WBGU), London: Earthscan.

Scottish Government, (2009) *Scotland's Climate Change Adaptation Framework - Energy,* <http://www.scotland.gov.uk/Publications/2009/12/08130940/2> [Accessed 8th September 2010].

Sempris, E. (2009) *Climate Change and Freshwater in Latin America and the Caribbean,* UN Chronicle, <www.un.org/wcm/content/site/chronicle/cache/bypass/lang/en/home/archive/Issues2009/pid/5075;jsessionid=13906207B3D31ADFD262DFE4830F498D?ctnscroll_articleContainerList=1_0&ctnlistpagination_articleContainerList=true> [Accessed 9th September 2010].

★ Mesoamerican Regional Visualization and Monitoring System (http://www.servir.net),

★ RedHum (http://www.redhum.org)

Sharpe, W. and Hodgson, A. (2006) *A Technology Forward Look – Towards a Cyber-Urban Ecology,* Foresight UK

Shroeter, D. and the ATEAM Consortium (2004) *Global Change Vulnerability – assessing the European human-environment system*, Potsdam Institute for Climate Impact Research, <http://unfccc.int/files/meetings/workshops/other_meetings/application/pdf/schroeter.pdf> [Accessed 28th August 2010].

Siddiqui, K. M. Mohammad, I. and Ayaz, M. (1999) Forest ecosystem climate change impact assessment and adaptation strategies for Pakistan, *Climate Research*, 12(2-3) pp.195-203.

Silver, N., Cox, M. & Garrett, E. (2010) *The Impact of Climate Change Overseas on the UK Financial Services Sector,* http://bis.gov.uk/foresight.

Simms, A. and Reid, H. (2006) *Up in smoke? Latin America and the Caribbean: The threat from climate change to the environment and human development*, The New Economics Foundation (NEF), London, UK.

Smil, V. (2000) *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production*, MIT Press.

★ Ruttan 1999

★ Scientific American June 18, 2009

Smith, D. & Vivekananda, J. (2007) *A Climate of Conflict – Links between climate change, peace and war,* International Alert.

Sterman, J., (2000) *Business Dynamics - Systems Thinking and Modeling for a Complex World,* Irwin McGraw-Hill

Tomczak, J., (2005) *Implications of Fossil Fuel Dependence for the Food System* http://energybulletin.net/node/17036 [Accessed 13th September 2010]

Trust for America's Health (2009) *Health Problems Heat Up: Climate Change and the Public Health*, Issue Report.

Tsai, HT. Liu, T.M. (2005) *Effects of global climate change on disease epidemics and social instability around the world,* Centre for the Study of Civil War, International Peace Research Institute, Oslo (PRIO).

UKCIP (1999) *Rising to the Challenge – Impacts of Climate Change in the South East in the 21st Century*, http://www.ukcip.org.uk/wordpress/wp-content/PDFs/SE_summary.pdf [Accessed 23rd February 2011]

uktradeinfo, (2010) *UK Imports and Exports General Trade,* <https://www.uktradeinfo.com/index.cfm?task=topcountriesqtr> [Accessed 30th July 2010].

Umpleby, S. (2007) *Reflexivity in Social Systems: The Theories of George Soros*, Systems Research and Behavioral Science 24, (pp. 515-522).

UN Framework Convention on Climate Change Subsidiary Body for Scientific and Technological Advice, (2004) *Application of methods and tools for assessing impacts and vulnerability, and developing adaptation responses*, http://unfccc.int/resource/docs/2004/sbsta/inf13.pdf, [Accessed 28th August 2010]

UNDP, (2009) *Human Development Report 2009: Overcoming barriers: Human mobility and development*, http://hdr.undp.org [Accessed 28the August 2010]

UNDP, (2010) *International Human Development Indicators, http:/hdr.undp.org/en/data/map* [Accessed 8th December 2010]

UNEP, (2008) *Climate Change in the Caribbean and the Challenge of Adaptation,* United Nations Environment Programme (UNEP), Regional Office for Latin America and the Caribbean, Panama City, Panama.

★ Government of Belize 2002

★ Goverment of Guyana 2002

★ Goverment of Jamaica 2000

★ UNEP 2005

UNEP, (2009) *Recent trends in melting glaciers, tropospheric temperatures over the Himalayas and summer monsoon rainfall over India,* Division of Early Warning and Assessment (DEWA), United Nations Environment Programme (UNEP), Nairobi, Kenya.

UNFCCC, (2004) *Scientific, technical and socio-economic aspects of impacts of, and vulnerability and adaptation to, climate change*, United Nations Framework Convention on Climate Change (UNFCCC), <http://unfccc.int/resource/docs/2004/sbsta/inf13.pdf> [Accessed 28th August 2010].

UNFCCC, (2007) *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries,* United Nations Framework Convention on Climate Change (UNFCCC), <http://www.unfccc.int/resource/docs/publications/impacts.pdf> [Accessed 9th September 2010].

UN-HABITAT, (2008) *The State of the World's Cities 2008/2009, United Nations Settlements Programme,* London: Earthscan.

UN-REDD, (2010) *UN-REDD Programme Factsheet: Supporting countries to get ready for REDD,* United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries, <www.un-redd.org> [Accessed 9th September 2010].

UNWATER (2009) *Water in a Changing World,* The United Nations World Water Development Report 3, http://www.unesco.org/water/wwap/wwdr/wwdr3/pdf/WWDR3_Water_in_a_Changing_World.pdf [Accessed 23rd February 2011]

US Climate Change Science Programme (CCSP), (2008) *Weather and Climate Extremes in a Changing Climate, Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands,* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA

Vickers, G., (1995) *The Art of Judgement: A Study of Policy Making,* APA Advances in Public Administration

Vörösmarty CJ, Green P, Salisbury J, Lammers RB. (2000) *Global water resources:* vulnerability *from climate change and population growth.* Science. 2000 Jul 14;289(5477):284-8.

Wade, S. et al,(1999) *Rising to the Challenge: Impacts of Climate Change in the South East in the 21st Century, Summary Report,* UK Climate Impacts Programme (UKCIP). <http://www.climatesoutheast.org.uk/index.php/publication> [Accessed 8th September 2010].

Walker, B., and Salt, D., (2006) *Resilience Thinking*, Island Press

Wallace, J. (2009) *Security Aspects of Climate Change,* State of the World Report 'Into a Warming World', <http://www.chinadialogue.net/article/show/single/en/2747> [Accessed 6th September 2010].

Waltner-Toews, D. (2004) *Ecosystem Sustainability and Health: A Practical Approach,* Cambridge University Press, UK.

Wang, J. et al, (2008) *Can China Continue Feeding Itself? The Impact of Climate Change on Agriculture*. World Bank Policy Research Working Paper 4470, Washington D.C.

Wasdell,D., Rghani,D., Wadhams, P., and Cox, P. (2007) *Planet Earth We Have a Problem,* Briefing to the All Party Parliamentary Climate Change Group

(APPCCG)

WBCSD, (2009) *Water, Energy and Climate Change: A Contribution from the Business Community,* World Business Council for Sustainable Development, <http://www.unwater.org/downloads/WaterEnergyandClimateChange.pdf> [Accessed 9th September 2010].

WBCSD (2010) , *Vision 2050: The new agenda for business* http://www.wbcsd.org/Plugins/DocSearch/details.asp?DocTypeId=25&ObjectId=MzczOTc

WBGU, (2007) *Climate Change as a Security Risk*

Wen, D.J. (2009) *Climate Change & China: Technology, Market, & Beyond, A Report for Focus on the Global South* <http://www.ifg.org/pdf/occasional_paper6-climate_change_and_china.pdf> [Accessed 9th September 2010].

Wicks, M. (2009) *Energy Security: A national challenge in a changing world,* Department of Energy and Climate Change (DECC).

World Bank (2008) *Can China Continue Feeding Itself? The Impact of Climate Change on Agriculture*, Jinxia Wang, et al, Policy Research Working Paper 4470

World Bank Group, (2009) *Governance Matters 2009: Worldwide Governance Indicators 1996 – 2008*, http://info.worldbank.org/governance/wgi/index.asp, [Accessed 28th August 2010]

★ Olesen and Bindi 2002

World Economic Forum, (2002) *Readiness for the Future Index*, Europe 2050 Task Force.

WWF International, (2009) *Mega-Stress for Mega-Cities: A Climate Vulnerability Ranking of Major Coastal Cities in Asia.* <http://assets.panda.org/downloads/mega_cities_report.pdf> [Accessed 9th September 2010].

Yusuf, A. and Francisco, H. A. (2009) *Climate Change Vulnerability Mapping for Southeast Asia,* Economy and Environment Program for Southeast Asia, <www.eepsea.org> [Accessed 9th September 2010].